Winter 11-2021

Cognitive Effects of Alcohol Use and Sleep Disruption in College Students

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COGNITIVE EFFECTS OF ALCOHOL USE AND SLEEP DISRUPTION IN COLLEGE STUDENTS

by

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A DISSERTATION

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Psychology

Under the Supervision of Professor Dennis E. McChargue

Lincoln, Nebraska

November, 2021

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University of Nebraska, 2021

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Alcohol use and sleep disruption are highly prevalent amongst college students, yet their combined effects on cognitive functioning and subsequent classroom performance have not been fully examined. Alcohol use has been shown to negatively impact cognitive functioning, especially in college students without fully matured brain regions. This has led to decreases in academic functioning and increases in college dropout. Disruptions in sleep functioning can lead to both lapses in attention and an overall decrease in attention, which can negatively impact learning in a classroom environment.

Participants were 96 undergraduate students who were invited to participate based on responses from a screening measure regarding drinking behaviors. Participants were selected to binge drinker/non-binge drinker and sleep problem/no sleep problem groups based on their responses to administered measures. Participants also completed a ~30-minute cognitive assessment via an iPad evaluating multiple cognitive domains (e.g., attention, memory), as well as complete a 7-day diary of sleeping and alcohol use behaviors prior to their assessment. One-way and univariate ANOVAs were conducted to determine main and interactive cognitive differences between the alcohol use and sleep

problems groups, as well as Multilevel Modeling to evaluate daily patterns and predictors of sleeping and alcohol use behaviors.

Results indicated non-significant main effects for subtests in both the binge drinking and sleep problems groups, and there were also non-significant interactive effects between the conditions. Per self-report, results also exhibited that participants tended to drink more alcoholic drinks, go to bed later, and get less sleep towards the weekends. Although the current study was unable to identify the synergistic effects of alcohol use and sleep problems on cognitive performance, it was able to detect independent effects and illuminate the daily relationship between alcohol use and sleep behaviors in college students. Several limitations were identified, and further research with larger sample sizes may be needed to clarify the complex relationship between alcohol use, sleep problems, and cognitive performance.

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CHAPTER 1: INTRODUCTION

As the number of students entering college continues to rise, dropout rates are reaching near epidemic levels (as much as 40%; Bernardo et al., 2017). Research has shown that individuals with college degrees have lower unemployment rates, higher lifetime earnings, and less physical and mental health problems throughout their lifetime (Lantz et al., 1998; Molla et al., 2001). Given the deleterious effects of dropping out of college, retention researchers have examined various factors and circumstances related to student departure (Boyraz et al., 2016; Taylor et al., 2012). Two of the most malleable factors that affect overall performance in college are alcohol use and sleep disruption.

The college years are a crucial developmental period for most students, as this is the first time many of them have been away from their parents and make independent decisions about their behaviors. As such, many students engage in experimentation with new experiences, with the most common being experimentation with alcohol use. Estimates show that nearly 80% of college students have drank alcohol in the past month, with over half of those students engaging in binge drinking (Siegel et al., 2011). This form of hazardous alcohol use can not only result in negative consequences like legal problems, engaging in risky physical and sexual behaviors, and interpersonal relationship issues, but can also impact imperative cognitive mechanisms that can lead to decreased academic functioning and possible college dropout.

Alcohol use has been shown to decrease performance in a variety of cognitive domains, with some studies indicating that heavy episodic use (i.e., binge drinking) is a greater detriment to cognitive functioning than regular drinking (Hermens & Lagopoulos, 2018). Of the domains affected by alcohol use, perhaps the most important to overall academic functioning are attentional and memory processes. Acute alcohol use has been shown to decrease selective, divided, and sustained attention, with these effects continuing even after the individual has metabolized alcohol from their body (McKinney et al., 2012; Nixon, 2013). Furthermore, people who binge drink show diminished abilities in episodic, declarative, and working memory functioning, which may impact their ability to recall information and lead to decreased academic performance (Heffernan & O'Neill, 2012). In addition to decreases in attention and memory, alcohol also impacts inhibition, planning, problem solving, and cognitive flexibility—all of which contribute to overall success in college. While it is evident that alcohol plays a major role in deficits of cognitive functioning, researchers have also identified sleep functioning as a key component in overall cognitive performance.

At least 25% of college students report poor sleep quality, and upwards of 65% report at least occasional sleep disturbances (Buboltz et al., 2009). Forquer, Camden, Gabriau, and Johnson (2008) found that this pattern of sleep disruption can result in cumulative "sleep debt", in which students are consistently operating on less than recommended levels of sleep. This sleep debt can result in feeling excessively sleepy throughout the day, as well as put students at higher risk of car accidents and other dangerous situations. Moreover, students with sleep disruption tend to experience emotional difficulties and have greater health problems than those with normal sleep patterns. In addition to the aforementioned consequences, sleep plays a vital role in cognitive functioning as well, with disruptions significantly interfering with vital cognitive processes that could result in overall decreases in academic performance.

Attention is perhaps the single cognitive domain that sleep disruption affects the most. The most common assessment of sleep related attentional loss is through measuring reaction times when a stimulus is presented. Individuals who are sleep deprived or experience sleep disruption tend to respond more slowly than those with normal sleep patterns (Dinges et al., 1997; Lim & Dinges, 2010). Additionally, people with sleep disruptions are more likely to have “lapses” in attention, in which they fail to respond to the stimulus or respond significantly slower than normal. These lapses may be fairly brief, but their cumulative effect can drastically hamper a student’s ability to pay attention to a lecture or study for a test, thereby reducing his overall academic performance. There is also evidence that memory is impacted by sleep disruption, as individuals with disrupted sleep patterns performed more poorly on a test of learning and recall than those without sleep disruption (McDevitt et al., 2015). Although both sleep disruption and alcohol use have extensive research concerning their independent effects on cognitive functioning, it is also worthwhile to examine research concerning their synergistic effects given the established relationship between sleep quality and alcohol use.

One of the largest behavioral factors than affects both the quantity and quality of sleep is alcohol use. Because alcohol has sedative effects, people do tend to go to sleep more quickly than those who did not drink; however, they tend to spend less time in each sleep stage and exhibit shorter overall sleep times (Peeke et al., 1980). Alcohol use particularly affects the REM (rapid eye movement) sleep, a stage that is believed to be when most memories are consolidated from the previous day (Ebrahim et al., 2013). Repeated alcohol use has also been shown to disrupt the secretion of melatonin (a key sleep hormone), as well as potentially interfere with circadian rhythms (Chan et al., 2013).

Even though alcohol use and sleep disruption can negatively affect cognitive functioning, surprisingly little research has examined the relationship of all three variables together. Similar to their independent effects, many of the results indicated that drinkers who experienced sleep problems performed more poorly on measures of attention, memory, and overall executive functioning than all other groups. The following literature review will expand upon alcohol use and sleep disruption within a college population. I will also further illustrate the negative effects alcohol use and sleep disruption has on cognitive functioning, as well as how alcohol use affects sleep performance.

College Alcohol Use

The college years constitute a critical developmental period where alcohol use and hazardous drinking behaviors significantly increase (Windle, 2003). As such, people in this period experience the highest rates of heavy alcohol use compared to any other at-risk groups of drinkers (Campbell & Demb, 2008; Dawson, Grant, Stinson, & Chou, 2004). This high-risk level of alcohol involvement is associated with a plethora of alcohol-related consequences that are specific (i.e., poor academic functioning) to this important life transition (Beck et al., 2008; Kahler et al., 2004). More importantly, research has consistently indicated that rates of Alcohol Use Disorders (AUDs) also peak during the college years (Dawson et al., 2004; Hagman, Cohn, Schonfeld, Moore, & Barrett, 2014).

Epidemiological evidence has shown that prevalence estimates of AUDs for college students range up to approximately 30% under the Diagnostic and Statistical Manual, 4th edition (DSM–IV) and DSM–5 diagnostic systems (Grant & Dawson, 2006; Hagman et al., 2014; Harris, Sherritt, Van Hook, Wechsler, & Knight, 2010; Hasin & Grant, 2015). These high rates of AUDs are particularly disconcerting because if an AUD in college is left undiagnosed, then it has the potential to lead to a more hazardous form of AUD severity (Campbell & Demb, 2008). Thus, it is critical that college treatment providers and administrators develop brief assessment tools that provide reliable and accurate diagnostic information to identify individuals who may be “at risk” or in need of treatment/referral to deter risky levels of alcohol use and/or prevent a more severe course of problematic alcohol use from developing in later adulthood.

Research indicates that 44% of college students binge drink, and 18 to 24-year-olds consume an average of 9.5 drinks—the highest among any population subset in the United States—when they binge drink (Siegel et al., 2011). College students’ binge drinking is associated with difficulties in executive control of working memory, as well as other aspects of cognitive functioning (Parada et al., 2012; Read, Beattie, Chamberlain, & Merrill, 2008). These impairments in cognitive functioning could lead to negative academic consequences and contribute to increased rates of college dropout.

Sleep Functioning

Sleep is an essential part of most animals' functioning, especially humans. Ironically, one of the primary ways to understand the benefits of sleep is to observe what happens when humans are deprived of sleep. Sleep deprivation has been shown to compromise an individual's immune system (Zager et al., 2009), decreasing white blood cells and increasing rates of cancerous cell growth. Individuals who are deprived of sleep also tend to secrete less growth hormone levels, resulting in decreases height and weight as an adult (Taylor, Jenni, Acebo, & Carskadon, 2005). One of the most common thoughts about the benefits of sleep is that it helps us to process memories and encode the events that happened throughout the day. Those who are sleep deprived have been shown to have poorer declarative and procedural memories than those who got a sufficient level of sleep (Gais et al., 2011). In addition to the benefits upon memory processing, people who get more sleep tend to have better working memories than people who are sleep deprived, enabling them to perform higher level cognitive tasks more easily (Turner et al., 2007).

To understand the cognitive effects of sleep deprivation, it is imperative that one first understands the processes and stages of sleep to get a clear picture of how the sleep cycle operates. In general, sleep can be broken down into two sleep states - rapid eye movement (REM) sleep and nonrapid eye movement (NREM) sleep. Furthermore, NREM sleep can be broken down into stages based on how deep the sleep state is. We can tell what stage a person is in when they are sleeping by examining three electrophysiological measurements first implemented in 1968 (Roehrs & Roth, 2001). The first measurement tool is an electroencephalogram (EEG), which measures electrical activity in the brain regarding alpha, beta, delta, and theta waves. An electrooculogram (EOG) measures electric signals that occur when the eyes move during sleep. Finally, an electromyogram (EMG) is used to measure the electrical activity of various muscle groups throughout the body. Using these instruments, a person can compare the differences in brain wave frequency and amplitude to assess the various stages of sleep and wakefulness.

According to Roehrs and Roth (2001), while a person is awake, beta waves are the predominant brain activity and large muscle group movement can be detected. As the person becomes more relaxed and enters the first stage of NREM sleep, alpha wave activity increases and muscle movement decreases. In this stage, sleep is also the "lightest" and the person is very easy to awaken. Moving into the second stage of NREM sleep, alpha waves become interrupted and theta waves can be detected. The third and "deepest" stage of sleep is also called slow wave sleep (SWS) in which delta waves are the predominant brain activity. In this stage, people are the difficult to awaken and do not respond to environmental stimuli. It is here that people enter REM sleep that is often accompanied by sleep paralysis that prevents muscle movement. This stage has also been called paradoxical sleep because even though this stage has brain wave activity most similar to being awake, it is also the stage where it is hardest to awaken the person. People cycle through these stages each night approximately every 90-120 minutes with slow wave sleep happening more frequently earlier in the night and REM sleep happening more frequently later in the night. While this pattern is true for most people, some populations like college students have circumstantial factors that get in the way of normal sleep functioning (Gomes et al., 2011; Kelly et al., 2001).

College Sleep Quality

In their study of college undergraduates, Buboltz et al. (2009) found that one-fourth of students surveyed reported poor sleep quality, with two-thirds reporting at least occasional sleep disturbances. These disturbances included prolonged sleep latencies, nocturnal awakenings, and the regular use of sleep medications for sleep initiation and stimulants for daytime alertness, creating a vicious cycle and setting the stage for substance dependence. Poor sleep quality has been correlated with a number of cognitive and emotional difficulties; including, emotion regulation problems, concentration and memory difficulties, and lower overall life satisfaction (Pilcher et al., 1997). In their study of college students characterized as normal sleepers, Pilcher and Ott (1998) found that sleep quality was more strongly correlated with measures of health and well-being than sleep quantity. College students have not only stated that sleep quality affects their ability to academically focus, concentrate, and remember things; but, with increases in self-reported sleep quality, they have demonstrated modest increases in GPA (Orzech et al., 2011).

The impact of nighttime sleep loss on daytime functioning has further implications for the college population. In their examination of overall sleep patterns within a university sample, Forquer, Camden, Gabriau, and Johnson (2008) found that over one-third of students reported being tired during the day. However, while decreased sleep duration is widely believed to result in the accumulation of sleep debt, there has been controversy in the actual meaning of the term. In an effort to clarify the concept of sleep debt, Lim and Dinges (2010) examined two unique daytime markers of the impact of sleep loss (homeostatic sleep pressure and behavioral alertness). Based on their findings, sleep debt was ultimately defined as “cumulative hours of sleep loss with respect to a subject-specific daily need for sleep” (Lim & Dinges, 2010). Cumulative sleep debt also has important implications for neurocognitive functioning, including decrements in risk assessment, insight, memory, and lateral thinking (Harrison & Horne, 2000).

Ignoring individual differences in nocturnal sleep need, there are important health implications for the experience of excessive daytime sleepiness (EDS) across the developmental span. While EDS is often the result of other predisposing sleep disorders, such as narcolepsy and obstructive sleep apnea, excessive daytime sleepiness has also been shown to be independently related to an increased utilization of health care services, including outpatient physician visits and hospitalizations (Ronksley et al., 2011). In their cross-sectional review of college students, Taylor and Bramoweth (2010) described the negative behaviors students engage in to counteract insufficient sleep, in that they reported frequent use of medication and alcohol to induce sleep and stimulants to increase daytime alertness. This consistent sleep disruption also accumulates over time and students accrue “sleep debt” that causes daytime sleepiness and increases risk of being involved in a car accident. Chronic daytime sleepiness can also lead to negative health consequences, including hospitalizations. In addition to these negative consequences, sleep disruption can also negatively impact cognitive functioning. For example, Lucidi, Malla, Violani, Giustiniani, and Persia (2013) report that young people between 16 and 29 years of age were the most likely to be involved in crashes caused by the driver falling asleep. It has also been shown that adolescent boys, when compared to their female peers, are particularly vulnerable to tragic accidents that result from excessive sleepiness, with up to 10% of boys reporting falling asleep at the wheel (Carskadon, 1990).

Sleep and Cognitive Functioning

In order to engage in higher level cognitive processing, individuals must first focus their attention towards a stimulus (Bradley et al., 2020). After sufficiently attending to an object and taking in its sensory information, working memory comes into play and eventually stores the information into long term memory. People who have been deprived of sleep have shown to have poorer attention, and therefore do not even have the opportunities to move information into their long-term memory stores (Lim & Dinges, 2010). Individuals who have had sufficient rest usually only exhibit slight fluctuations in attention that mirror fluctuations in circadian rhythms; however, testing has shown that attention exhibits significant declines when individuals have been awake for as little as 16 hours (Basner et al., 2013).

The most common way researchers test attention and alertness is through a psychomotor vigilance test (PVT). This is a computerized task in which individuals must press a key each time they see a stimulus on screen. The PVT has been used to assess attentional deficits in both long-term sleep deprivation (Grant, Honn, Layton, Riedy, & Van Dongen, 2017) and shorter term sleep restriction (Dinges et al., 1997). One study by Wesensten, Killgore, and Balkin (2005) used the PVT task to assess participants during 83 hours of sleep deprivation. General results indicated decreasing performance on vigilance and attention as the individuals stayed awake longer, but there were surprising fluctuations of individuals tending to perform well just before midnight each day and performing at their poorest just before 8:00 AM each morning. The authors theorized that this pattern was mainly a result of circadian effects as individuals exhibited the greatest declines in performance during the hours that they would usually be sleeping (11:00 PM -

8:00 AM). A similar study showed that performance on the PVT mirrored results of Wesensten, Killgore, and Balkin (2005) when individuals had restricted sleep patterns (<6 hours/night) over the course of two weeks (Hilditch et al., 2016). These results illustrate that chronic sleep disruption can lead to the same types of negative effects as two days of sleep deprivation.

Wesensten, Killgore, and Balkin (2005) also found that as the time without sleep increased, individuals were more likely to become non-responsive in the PVT for a period of 1-2 seconds. They termed these occurrences as "lapses" and suggested that the lapses were caused by the interaction of two biological processes. The first process is the circadian rhythm in which attention tends to wax and wane throughout the day naturally. The second process is due to a homeostatic sleep drive in which the body's need for sleep increases as an individual stays awake longer. While this may seem intuitive in nature, it was worthwhile to note that the interaction of these two processes made it more likely for lapses to happen when attention from circadian rhythms was at its lowest and the homeostatic sleep drive was at its highest. Studies have also found that when restricting sleep to less than 5 hours/night, the homeostatic sleep drive compresses natural circadian rhythms and lowers sleep efficiency (Bes et al., 2013).

A study by Dawson and Reid (1997) examined the relationship between attention and motor tracking when individuals are sleep deprived. Participants were tested with a simple hand-eye coordination task over a period of 28 hours of sleep deprivation. Participants returned to the lab when well rested to perform the tasks again, but during the second visit they consumed alcoholic beverages to the point of intoxication. When comparing performance of participants during each of their sessions, the authors discovered that for each hour an individual stayed awake beyond 10 hours, their performance declined such that at 17 hours of deprivation they had performance as though they had a blood alcohol content of 0.05%, and at 24 hours of deprivation their performance mirrored that of when they had a blood alcohol content of 0.10%. To put into context, these results indicate that after 24 hours of sleep deprivation, individuals perform hand-eye coordination tasks as poorly as if they were legally intoxicated.

As mentioned before, sleep deprivation can lead to problems with attention and vigilance and consequently lead to memory dysfunction as a result of inattention. There is also evidence that sleep problems can affect memory itself, even when the person pays adequate attention to the stimuli (Diekelmann & Born, 2010). Additionally, there has been support that adequate sleep both before and after learning is crucial to knowledge properly being stored in memory (Diekelmann & Born, 2010; Drummond et al., 2013) One study showed that when participants were deprived of sleep for 35 hours, they exhibited significant reductions in verbal learning when compared to their baseline performance (Drummond et al., 2000). Brain imaging during the tasks showed decreased activation of the temporal lobe when the individuals were sleep deprived and the authors concluded that reduced activity hampered their ability to learn. Harrison and Horne (2000) found that sleep deprivation affected temporal memory as well as declarative memory. Their experiment had participants remember two sets of faces with delays in between and after each set of faces. The sleep deprived group performed just as well in recalling if they had seen a face or not, but they performed significantly worse than the non-deprived group at remembering which set of faces a particular face came from, even when reporting being more confident that they were correct. Much of the current thinking is that sleep deprivation hinders the hippocampus' ability to store memories and learning without satisfactory sleep prior to learning (Mander et al., 2014). Findings have also suggested an emotional component to learning that is also impaired by sleep deprivation with some studies suggesting that a nap may aid in learning (Mander et al., 2014).

In addition to pre-learning sleep deprivation affecting memory and learning, there is also evidence that sleep deprivation after learning materials may impact the ability to later recall what was learned. Participants who were deprived of sleep for 12 hours after learning a paired word task performed significantly worse at recall than those who were not instructed to be deprived of sleep (McDevitt et al., 2015). Mascetti and colleagues (2013) strengthened the argument of sleep deprivation affecting the hippocampus leading to decreased learning with their findings supporting hippocampal deactivation with deprivation of the slow wave sleep stage. Many of the previous findings indicate that sleep disruption can have dramatic negative effects of cognitive functioning, specifically on attention and memory processes. Because college students are at an increased risk for both sleep disruption and alcohol use, it is necessary to examine the effects alcohol use has on overall sleep functioning.

Sleep and Alcohol

One of the biggest factors that can affect the quality and quantity of sleep is alcohol. Alcohol can have many detrimental effects to sleep, not only involving a disruption of certain sleep stages, but also affecting physiological and chemical processes involved in sleep. Many studies involved in the physiological effects of sleep use alcohol administration procedures and monitor how the alcohol affects the following sleep period. A usual alcohol administration will give the participants between one and six standard drinks (depending on their body weight) between 30 and 60 minutes before going to sleep, which results in blood alcohol concentration (BAC) levels usually around 0.10%. Studies have found that participants usually go to sleep faster than those who do not drink alcohol, but higher levels of alcohol consumption have resulted in decreased overall sleep times (Peeke et al., 1980). Prior research also has shown increased wake periods and especially light sleep in stage one of NREM sleep that occurs during the second half of the night (Williams et al., 1983). This phenomenon has been labeled the "rebound effect" and happens in the second half of sleep because the alcohol has been completely metabolized at that time, only if the participant achieved a peak BAC of 0.10%. One explanation for the "rebound effect" is that it is the body's way of trying to adjust to normal sleep after the alcohol has been eliminated from the body and loses its sedative qualities (Roehrs & Roth, 2001). The problem is that certain physiological factors tend to change in the opposite direction as they would for normal sleep, resulting in an overcompensation that causes sleep disruption and premature awakening. Support for this theory has been shown because alcohol is metabolized from the body at a fairly constant rate (usually about 0.015% per hour), which would mean that alcohol is completely metabolized about five hours into sleep, which coincides with sleep disruption attributed to the "rebound effect".

In addition to disruption in the second half of sleep, alcohol also affects the amount of time individuals spend in each stage of sleep. The most predominant finding is that alcohol produces a suppression of REM sleep, particularly in the first half of sleep (Ebrahim et al., 2013). It is also worth noting that while second half of sleep REM disruption is not as pronounced as first half, there is also less alcohol in the blood due to it being metabolized. Perhaps as a compensator to reduced REM sleep, studies have shown increases in SWS (stage 3 of NREM) in the first half of seep (Ebrahim et al., 2013). However, results may be misleading because research has also found that the increase in SWS coincides with normal SWS times for individuals (e.g., people with insomnia generally have less SWS than normal sleepers; Roehrs, Yoon, & Roth, 1991).

Aside from the physiological effects of alcohol on sleep, alcohol also interferes with key hormonal processes necessary for healthy sleep. One of the primary hormones produced by the brain for sleep regulation is melatonin. Melatonin is secreted in varying amounts, primarily dictated by circadian rhythms, in which production is increased in the evening hours and decreased shortly before awakening. Ingesting alcohol shortly before bed has been shown to have sedative effects and produce sleepiness in participants (Chan et al., 2013). Consequently, the brain reduces production of melatonin because there is no need for more sleep-inducing agent. This results in sleep disruption and premature awakening in the second half of sleep because the alcohol has been metabolized and there is little melatonin in the system to maintain regular sleep patterns.

Alcohol also affects the neurochemicals in the central nervous system associated with sleep, particularly interfering with the neurotransmitters GABA and glutamate. Alcohol has been shown to amplify GABA neurotransmitters (which is the main inhibitory neurotransmitter in the brain), which results in an even more pronounced effect in the inhibition of neuronal signals (Mihic & Harris, 1997). Because GABA appears in various regions of the brain involved in SWS (e.g., thalamus, hypothalamus, brainstem), many researchers believe that it can be one explanation of increased SWS while under the influence of alcohol. Conversely to GABA, glutamate is the main excitatory neurotransmitter in the brain and acts to promote activation of neurons. Alcohol seems to act as an antagonist to glutamate, which makes it not perform its job of activating neurons. Coupled with the increase in functioning of GABA, this serves as a mechanism to promote sleep at first, but is still suspect to the "rebound effect" in the second half of sleep (Kubota et al., 2002)

Alcohol also has detrimental effects on multiple aspects of cognitive performance. Research has shown that even losing one or two hours of sleep a night can decrease alertness and performance, and these effects can accrue over multiple nights of sleep loss (Roth & Roehrs, 2000). One real world application showed that pilots who had drank alcohol the night before performed significantly worse than those who drank a placebo, even though both groups' BAC levels were 0.0% at the time of testing (Yesavage & Leirer, 1986). In addition to all the well-documented deleterious health consequences of sleep deprivation, research also has shown that lack of sleep due to alcohol consumption can lead to decreased grades in college students (Singleton & Wolfson, 2009).

Both alcohol use and sleep disruption can have serious effects on cognitive functioning, in addition to overall wellbeing. Alcohol use also affects sleep functioning proximally by shortening overall sleep duration and quality, as well as distally by interfering with key hormones needed for sleep. Alcohol also affects neurotransmitters responsible for both excitatory and inhibitory signals to key areas of the brain necessary for cognitive functioning. Although there is much evidence supporting the negative cognitive effects of alcohol use and sleep disruption independently, a surprisingly sparse number of studies examined all three variables collectively.

Sleep, Alcohol, and Cognition

To date, very few studies have examined the interactive effects of alcohol use and sleep disruption on specific cognitive factors. A study by de Oliveira and colleagues (2016) examined the cognitive performance of a sample of truck drivers who did or did not have binge drinking episodes while also measuring sleep problems. They found that binge drinkers made significantly more errors on a test of sustained attention, as well as exhibited significantly longer inhibition response on a Stroop test. Although the authors did not find significant differences in sleep functioning, it appeared as though they only used measures to determine categorical frequencies (a X^2 test) rather than using the measures as independent variables. Clark and colleagues (2017) found that both risky alcohol use and sleep problems led to greater executive functioning problems, as measured by the BRIEF-SR, and that these problems were not related to cognitive skills or structural brain characteristics.

Morales-Munoz, Koskinen, and Partonen (2017) found that individuals with increased sleep problems perform more poorly than those with normal sleep functioning, and when factoring in alcohol abuse over the past 30 days, individuals were more likely to have an increase in sleep problems and a decrease in short-term memory functioning. A final study by Singleton & Wolfson (2009) examined the effects of both alcohol use and sleep problems on overall academic performance, as measured by GPA. Results showed that frequency of alcohol consumption is not only associated with decreased sleep duration, increased daytime sleepiness, and overall bedtime delay, but that alcohol consumption predicted lower GPA via lower sleep duration and greater sleepiness.

It is evident that alcohol use and sleep disruption have independent and synergistic effects on both academic achievement and cognitive performance. The following study not only replicates the findings of previous literature, but expands upon the specific cognitive mechanisms that are affected. By being able to pinpoint the exact relationship between the three variables, future research may be done towards designing interventions that may help identify behavioral strategies that will increase students' success in college.

Assumptions, Aims, and Hypotheses

Before discussing the aims of the current project, several assumptions need to be considered. The first assumption is that alcohol use and sleep disruption both play a part in classroom functioning and can contribute to college dropout. Based on data from a prior study, we found that the relationship between alcohol use and classroom performance is mediated by sleep disruption. Using a sample of 288 undergraduates, we created latent variables to evaluate alcohol use, sleep disruption, and classroom performance from a battery of measures designed to assess all facets of the constructs. Using structural equation modeling, we found that the sleep disruption latent variable fully mediated the relationship between alcohol use and classroom performance, such that the direct effect was no longer significant after accounting for sleep disruption. The final model indicated that increased alcohol use led to increased sleep disruption, which led to decreased classroom performance. Findings from this study indicated that alcohol use and sleep disruption do indeed both have a relationship with classroom performance.

A second assumption is that binge drinking (either across one or multiple weekends) impacts sleep functioning significantly during the school week. For example, we know that drinking impacts the immediate night's sleep, but how long do the effects drinking on a Friday and/or Saturday night last into the next week? A second study followed participants' nightly drinking and sleeping behaviors to determine alcohol influenced patterns of sleep disruption. Forty-two undergraduates wore actigraphs over a two-week period to measure sleep patterns, as well as completed sleep diaries to corroborate actigraph data and recorded number of drinks for a given night. Using multilevel modeling to determine alcohol related predictors of sleeping behaviors, results indicated that drinking alcohol reduced both the sleep quality and total sleep time of participants. Furthermore, it was determined that the sleep quality over the next two nights after drinking was significantly lower than an average night in which the participants did not drink. These results signify that weekend binge drinking can have lasting effects on sleep quality, even into the next school week.

Based on these prior findings, we can also assume that the reason alcohol use and sleep disruption lead to decreased classroom performance is because these behaviors impact students' cognitive functioning. In addition to the known effects of alcohol use and sleep disruption have on classroom performance when assessed individually, we also believe that there is a multiplicative effect for individuals who both engage in binge drinking and report sleep disruption. Thus, one aim of the current study is to both replicate previous findings that alcohol use and sleep disruption decrease cognitive functioning, as well as test the assumption that there is a multiplicative effect of the two factors on cognitive functioning. We will address this aim through the following hypotheses:

Hypothesis 1a: Binge drinkers will perform significantly worse on individual cognitive domains (attention, short-term and working memory, episodic memory, executive functioning, language skills, and processing speed) than those who do not drink alcohol.

Hypothesis 1b: Participants who experience sleep problems will perform worse on individual cognitive domains (attention, short-term and working memory, episodic memory, executive functioning, language skills, and processing speed) compared to those with no sleep problems.

Hypothesis 1c: There will be a multiplicative effect between alcohol use and sleep disruption such that individuals who are binge drinkers and experience sleep disruption will have the lowest performance on measures of all cognitive domains.

In addition to assessing the independent and multiplicative effect of alcohol use and sleep disruption on cognitive performance, a second aim of the current study is to identify patterns of relationships between daily alcohol use and sleeping behaviors, specifically bedtime, wake time, number of hours slept, and subjective sleep quality. This aim will be addressed by the following hyposthesis:

Hypothesis 2: When examining daily alcohol use and sleeping behaviors, there will be systematic linear changes. Specifically, alcohol use, bedtimes, wake times, and numbers of hours slept will tend to increase as the slope regresses towards the weekend, and subjective sleep quality will tend to decrease as the slope regresses towards the weekend.

CHAPTER 2: METHODS

Participants and Procedure

Participants (n = 96) were recruited from undergraduate psychology students at the University of Nebraska – Lincoln. The sample was primarily female (85.4%) with an average age of 20.4 years. The sample self-identified as 78.1% European American, 11.5% Asian American/Asian, 7.3% Latino(a), and 3.2% African American. The majority of individuals identified as heterosexual (83.3%) with 16.7% identifying themselves as part of the LGBTQ community. Additionally, 25% of the sample endorsed being part of a fraternity or sorority.

All procedures were approved by the University of Nebraska – Lincoln Institutional Review Board (IRB). Participants were selected based on responses to a mass screening questionnaire distributed via the psychology department's SONA Systems research participation program in exchange for credits counting towards one of their psychology classes. For this particular section of the screening instrument, participants were asked questions about their sleeping and drinking habits. Participants who endorsed a binge drinking episode (5 or more drinks for males, 4 or more drinks for females in a given sitting) over the past month were asked to participate, as well as those who reported no drinking at all to serve as controls. Participants were emailed asking for their participation in the study, and self-enrolled for given timeslots available for the study.

Once a research appointment was scheduled, participants were emailed 10 days prior to their appointment, with a blank "sleep and drinking diary" and instructions for how to complete it. The diary asked for bedtime, wake time, subjective sleep quality, and number of alcoholic drinks consumed that night. Participants were asked to report on these items every morning, starting 7 days prior to their in-lab appointment. Participants were informed they would be given bonus credits for arriving with a completed sleep diary, and those who did not were asked to complete one retrospectively before the in-lab assessment could begin.

Participants arrived at the lab and read through an online informed consent page via Qualtrics. The IRB authorized a waiver of signed consent at the request of the researcher, as some of the participants were considered minors by the state of Nebraska (aged 18). They then completed the demographics section of the questionnaire battery, followed by the questionnaires themselves presented in a random order as to control for order effects. After completion of the questionnaire battery (~30 minutes), participants were introduced to the NIH Toolbox Cognitive Battery (Weintraub et al., 2013) on an iPad tablet. A researcher administered the tasks, reading instructions aloud when presented, and ensuring all practice items were completed. The tasks were presented in the order they appear in the following cognitive assessment materials section. The cognitive task battery was designed to take approximately 30 minutes to complete. After completion of the cognitive battery, participants were debriefed about the study, thanked for their participation, and given credit via SONA.

Power Analysis

After analyzing pilot data collected of 44 participants, effect sizes of cognitive performance variables were slightly below moderate to moderate (η^2 = .04 - .06). Using G*Power version 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007) with 80% power, a 5% Type I error probability, and an effect size of .25 (equivalent to η^2 = .05), a total sample of 130 would be sufficient to find main and interactive effects for the ANOVAs. As the current sample was 96 participants, some ANOVA models may be underpowered.

Cognitive Assessment Materials

Picture Vocabulary Task. The Picture Vocabulary Task was administered to assess participants' language skills by recalling information that was previously learned (Gershon et al., 2014). This measure of language skills is administered in a computerized adaptive format, meaning the next question a participant receives depends on his or her response to the previous question. The respondent is presented with an audio recording of a word and four images on the iPad screen, and is asked to touch the picture that most closely matches the meaning of the word. Because the test uses a variable-length Computer Adaptive Technology, some participants see fewer items than others. The specific words presented depend on the participant's performance. The number of items presented depends on age and performance. For most participants, the measure will last approximately 5 minutes and will contain about 25 items. The computer will administer each item one by one, in an untimed fashion, until the test is completed.

Item Response Theory is used to score the Picture Vocabulary Task. A theta score is calculated and represents the overall ability of the participant's language skills, with higher scores indicating more developed abilities. A theta score is measured on a similar scale to a z-score, which is a statistic with a mean of zero and a standard deviation of one. The resulting theta score is then converted to an age-corrected standard score for easier interpretation.

Flanker Inhibitory Control and Attention Test. The Flanker was administered as a measure of executive functioning, specifically assessing inhibitory control and attention (Zelazo et al., 2014). The task requires the participant to focus on a stimulus while inhibiting attention to the stimuli flanking it. All participants are instructed to choose one of two buttons on the screen that corresponds to the direction in which the MIDDLE of five arrows is pointing.

On congruent trials, all the arrows are pointing in the same direction. On incongruent trials, the flanking arrows are pointing in the opposite direction of the middle arrow. Congruent and incongruent trials are mixed. The word *middle* appears on the screen for all participants to remind participants where to focus (a star in the middle of the screen).

A two-factor scoring method is employed that uses accuracy and reaction time, where each of these “vectors” range in value between 0 and 5. The accuracy and reaction time vectors are then summed, with a final score ranging in value from 0-10. For the accuracy score, the participant receives a value of 0.125 for each correct response (5 points divided by 40 trials). If the accuracy score for any participant is less than 4 (80% accuracy), the reaction time score is excluded, and the final total score will only reflect the accuracy performance. No participant in the current sample scored less than 80% for accuracy.

For the reaction time score, participants’ median reaction time values are computed using only correct trials with reaction times greater than or equal to 100 ms and reaction times no larger than 3 standard deviations away from their mean reaction time. Because time data tends to be positively skewed, a log (Base 10) transformation is applied to each participant’s median reaction time score to create a more normal distribution. The log values are then rescaled to conform to the 0-5 scale, with larger values indicating quicker reaction times. The average reaction time score was also computed by averaging each of the raw reaction times for each of the 20 trials. As with the vector score, only correct trials were included in the average, and times greater than 3 standard deviations greater than the average reaction time were excluded. For the current study, both computed scores and age corrected standard scores were used to assess for differences in performance, with higher values indicating better ability to attend to relevant stimuli and inhibit attention from irrelevant stimuli. Mean reaction times were also used to determine differences in reaction times between the binge drinking and sleep problems groups.

List Sorting Working Memory Test. Participants completed the List Sorting task as a measure of working memory (Tulsky et al., 2014). This task requires the participant to recall and sequence different visually and orally presented stimuli. Pictures of different foods and animals are displayed with both an accompanying audio recording and written text that name the item. The participant is asked to say the items back to the examiner in size order from smallest to largest. Correct responses are summed for a value between 0-26, with the resulting total being converted to an age-corrected standard score. Higher scores on this task indicate better abilities to immediately store, process, and manipulate information, which is indicative of higher functioning working memory capabilities.

Pattern Comparison Processing Speed Test. The Pattern Comparison Test was administered to assess participants' processing speed abilities (Carlozzi et al., 2014). This task assesses the participant's capability to quickly process if two images are the same or not. Participants are shown two pictures, and have to press a YES or NO button on screen to indicate if they are the same. If two images are NOT the same, there are noticeable differences in the images (e.g., three balls vs. five balls). A raw score is calculated with the total number of correct responses given in 85 seconds, which is then converted to an age-corrected standard score. Higher scores on this task are associated with faster processing abilities, which may be impacted by sleep problems and/or alcohol use.

Picture Sequence Memory Test. Participants completed the Picture Sequence Memory Test to assess episodic memory, which involves the ability to acquire, store, and recall new information (Dikmen et al., 2014). This task involves recalling increasingly lengthy (between 6-18 items in each trial) series of illustrated objects and activities that are presented in a particular order on the iPad screen, with corresponding audio recorded phrases played. Participants are given credit for each adjacent pair of pictures they correctly place, regardless of their actual place in the sequence (e.g., pictures 4 and 5 could be placed in spots 1 and 2, and would still get credit for a correct response. As with the Picture Vocabulary Task, the Picture Sequence Memory Test uses Item Response Theory to produce a theta score, which is then translated to an age-corrected standard score.

Oral Symbol Digit Test. Participants completed the Oral Symbol Digit Test to assess verbal processing speed abilities. This task consists of a “key” of 9 unique symbols, each paired with a number from 1-9, and requires the participant to look at a long series of symbols without numbers and call out orally which number belongs with each symbol. The participant must call out the numbers sequentially and as quickly as possible, looking at a laminated sheet, while the examiner records the participant’s response as correct/incorrect directly on the iPad using the touch screen. The participant has 120 seconds to call out as many correct numbers as he/she can, in order, without skipping any. Participants receive 1 point for each correct response producing a raw score between 0-144. The raw score is most commonly used for interpretation of the task, with higher scores indicating better processing speed abilities.

Auditory Verbal Learning Test. Participants completed the Auditory Verbal Learning Test to assess episodic memory. This task consists of a list of 15 unrelated words that are presented by audio recording over three consecutive learning trials. Participants receive 1 point for each correct response, obtaining a raw score between 0-45. The raw score is most commonly used for interpretation of this task, with higher scores representing better episodic memory abilities.

Psychological Measures

AUDIT. Participants completed the Alcohol Use Disorders Identification Test (Saunders et al., 1993). This scale is a 10-item, standardized screening measure designed to assess hazardous alcohol use within the past year. For this study, the time frame was modified to ask participants about their drinking behaviors over the past 30 days. Item responses use a Likert scale with options ranging from 0 – 4 based on the frequency or severity of each question. Scores on the items are summed, with higher scores indicative of elevated levels of hazardous drinking behaviors. Standard interpretation dictates that scores 8 and above are indicative of hazardous alcohol use (Babor, 2001); however, lower cutoffs have been suggested to be more sensitive for assessing problematic alcohol use in college populations (Dybek et al., 2006). The measure has been shown to assess for hazardous drinking—especially in a college and adolescent sample—with an above average internal consistency (Cronbach’s alpha = 0.81; Kokotailo et al., 2004). The

AUDIT has also been shown to have excellent validity at identifying harmful alcohol use with a sensitivity of 0.92 and a specificity of 0.94 (Saunders et al., 1993).

RAPI. The Rutgers Alcohol Problems Index (White & Labouvie, 1989) is a measure of problems associated with alcohol use in adolescents and young adults. This unidimensional scale consists of 23 items that ask the respondent how frequently a particular situation pertains to him or her in the past year. Responses range from 0 (none) to 3 (more than five times) and have been shown to have good internal consistency (Cronbach's alpha = 0.92; White & Labouvie, 1989). This measure was chosen to assess for some of the personal and social consequences resulting from maladaptive drinking behaviors.

B-YAACQ. The Brief-Young Adult Alcohol Consequences Questionnaire contains half the items of the original measure (Read et al., 2006). This measure is used to assess negative consequences associated with alcohol use. The B-YAACQ consists of 24 dichotomous items indicating if the participant experienced alcohol related consequences over the past year ranging from hangovers to physiological dependence. Again, the participants were asked to rate these items based on their experiences over the past 30 days.

PSQI. The Pittsburgh Sleep Quality Index (Buysse et al., 1989) assesses general sleep quality during the past month. It contains 19 self-rated questions that cover a variety of factors associated with sleep quality, as well as estimations of bedtimes, sleep duration, and sleep latency. The questions are grouped into seven component scores ranging from 0-3, and produce a total score with larger numbers indicating worse sleep quality. Total scores of 7 or above have been shown to be indicative of sleep problems

(Buysse et al., 1989). The measure demonstrates good internal consistency (Cronbach's alpha = 0.83; Buysee et al., 1989), and has been shown to remain reliable across follow-up administrations.

SHI. The Sleep Hygiene Index (Mastin et al., 2006) is a 13-item scale assessing how frequently individuals engage in behavior that compromise sleep hygiene and produces scores from 13 to 65. Items are summed with higher scores indicating more maladaptive sleep hygiene. The measure demonstrated fair internal consistency (Cronbach's alpha = 0.66; Mastin, Bryson, & Corwyn, 2006). It has also exhibited significant correlations with scores on the PSQI.

ESS. The Epworth Sleepiness Scale (Johns, 1991) is an 8-item measure of daytime sleepiness. Participants are asked how likely (scale of 0-3) they would be to doze in certain situations (e.g., watching T.V.) with higher scores indicating higher levels of sleepiness. The measure was included to assess daytime sleepiness presumably as a function of nighttime sleep disturbances.

Statistical Analysis Plan

Preliminary analyses were conducted to assess for statistical assumptions (e.g., normality, skewness, kurtosis), as well as to determine if there were any systematic demographic differences between groups. It is worth noting the distinction between the GPA and Expected GPA variables, as all participants who were first semester freshmen were instructed to leave the GPA question blank (as they had not completed a semester yet to have an overall GPA). Therefore, approximately one-third of the sample did not respond to this question, which may explain why differences were found for Expected GPA, but not cumulative GPA. Also, the measure of sleep efficiency came from reported number of hours slept divided by total time in bed as reported on the PSQI. Next, correlations of all demographic, psychological, and cognitive measures were analyzed to assess for effect sizes and possible issues (e.g., multicollinearity). Demographic variables were examined as independent variables for cognitive measures to assess for potential covariates if significant.

Hypotheses 1a-1c

To test for mean differences, one-way ANOVAs were conducted on all cognitive outcome variables using binge drinker/non-binge drinker and sleep disruption/no sleep disruption separately as independent variables. Prior studies have utilized one-way ANOVA approaches to test for mean differences between cognitive performance variables on the NIH Toolbox Cognitive Battery (Calvert et al., 2019; Foy & Foy, 2020). Results from these ANOVAs assessed the independent effects of drinking and sleep disruption on each cognitive task. Furthermore, univariate ANOVAs were conducted on all cognitive outcome variables using both binge drinker/non-binge drinker and sleep disruption/no sleep disruption variables in the model to test for interaction effects. Univariate ANOVAs were used in a study by Apple and colleagues (2017) to assess for the impact multiple variable have on cognitive performance on the NIH Toolbox Cognitive Battery. Consistent with Tabachnick and Fidell (2007), Bonferroni corrections were made to minimize the chance of Type I error when making multiple comparisons with each ANOVA model. In order to preserve a family-wise error rate of 5%, a *p* value of .00185 (.05/27) was be used for all comparisons made for Hypotheses 1a-1c.

Hypothesis 2

To assess for patterns of relationships Multilevel Modeling (MLM) was used to test the daily report of alcohol use and sleeping behaviors nested within participants. MLM has been previously used to assess longitudinal data gathered through sleep diaries (Slavish et al., 2020; Winzeler et al., 2014). The daily variables (bedtime, wake time, hours of sleep, subjective sleep quality, and number of alcoholic drinks consumed) were entered as Level-1 variables. The Level-2 participant variables were scores on overall cognitive performance. Because MLM uses a partial pooling approach that shifts model estimates towards each other (resulting in more efficient estimates), issues with multiple comparisons are usually not problematic (Gelman, Hill, & Yajima, 2009). Therefore a *p* value of .05 was retained for models used in Hypothesis 2.

CHAPTER 3: RESULTS

Initial Analyses

Sampling Distribution. To assess for systematic differences between groups in the sample, Chi-square tests were used for all categorical variables and ANOVAs were used for continuous measures. Separate analyses were completed to determine differences between binge drinkers compared to non-binge drinkers, as well as those whose scores indicated sleep problems versus no sleep problems. When comparing alcohol use behaviors for categorical demographic variables (Table 3.1), there were significant differences between groups in stated Race/Ethnicity (p = .003). Specifically, there was a higher proportion of individuals identifying as Asian in the non-binge group, and a higher proportion of participants identifying as European American in the binge group. There were no significant differences in gender, year in college, Greek status, hours employed, or sexual orientation (p > .05).

Table 3.1. *Results of Chi-Square Test and Descriptive Statistics for Alcohol Use Groups*

	Binge Drinker *n*	Non-Binge *n*	χ^2 (*p*)
Gender			
Male	7	7	.007(.93)
Female	40	42	
Year in College			
Underclassman	26	25	.178 (.67)
Upperclassman	21	24	
Race/Ethnicity			
European American	45	30	13.62 (.003)
African American	0	3	
Latinx	2	5	
Asian	0	11	
Greek Status			
Greek	13	11	.347 (.56)
Non-Greek	34	38	
Hours Employed			
0	21	20	1.77 (.41)
1-20	20	26	

>20	6	3	
Sexual Orientation			
Heterosexual	40	40	.208 (.65)
LGBTQ	7	9	

When comparing sleep problems for categorical demographic variables (Table 3.2), there were significant differences between groups in Greek status ($p = .02$). Specifically, there was a higher proportion of Non-Greek individuals that reported sleep problems, compared to the participants that reported no sleep problems. There were no significant differences in gender, year in college, race/ethnicity, hours employed, or sexual orientation ($p > .05$).

Table 3.2. *Results of Chi-Square Test and Descriptive Statistics for Sleep Problems Groups*

	Sleep Problems *n*	No Sleep Problems *n*	χ^2 (*p*)
Gender			
Male	7	7	.115 (.73)
Female	45	37	
Year in College			
Underclassman	32	19	3.23 (.07)
Upperclassman	20	25	
Race/Ethnicity			
European American	41	34	.558 (.91)
African American	2	1	
Latinx	4	3	
Asian	5	6	
Greek Status			
Greek	8	16	5.59 (.02)
Non-Greek	44	28	
Hours Employed			
0	23	18	4.14 (.13)
1-20	27	19	
>20	2	7	
Sexual Orientation			
Heterosexual	42	38	.537 (.46)
LGBTQ	10	6	

Effects for Alcohol Use Groups. When evaluating for differences between continuous variables, scores on alcohol measures, and scores on sleep measures between binge drinkers and non-binge drinkers (Table 3.3), there were significant differences in expected semester GPA (p = .018), as well as reported number of hours spent studying in an average week (p = .034). Specifically, individuals who reported binge drinking had significantly less reported number of hours spent studying and significantly less expected GPA for that semester. As expected, there were significant differences between the binge drinking groups, with the binge drinking group endorsing higher scores on the AUDIT, RAPI, and B-YAACQ (p < .001). There were no significant differences between age, current GPA, percentage of free time busy, number of caffeinated beverages drank per day, sleep efficiency, and scores on the PSQI, ESS, and SHI (p > .05)

Table 3.3. *Demographic and Psychological Measure Means and Differences for Alcohol Use*

	Binge Drinker M (SD)	Non-Binge M (SD)	ANOVA *F (p)*	*df*
Age	19.98 (2.19)	20.43 (2.44)	.900 (.345)	(1,94)
GPA	3.355 (.422)	3.523 (.432)	2.47 (.121)	(1,62)
Expected GPA	3.50 (.371)	3.672 (.349)	5.77 (.018)	(1,94)
Hours Studying	13.89 (9.01)	18.39 (11.03)	4.66 (.034)	(1,92)
% of Time Busy	39.57 (25.91)	41.16 (27.04)	.086 (.770)	(1,94)
Caffeine Drinks	1.33 (1.23)	1.34 (1.24)	.001 (.978)	(1,94)
AUDIT	7.68 (2.64)	1.43 (1.35)	215.94 (< .001)	(1,94)
RAPI	4.83 (4.22)	1.71 (3.37)	16.06 (< .001)	(1,94)
BYAACQ	6.52 (4.06)	1.31 (2.04)	63.73 (< .001)	(1,93)
PSQI	6.68 (2.92)	6.10 (3.18)	.868 (.354)	(1,94)
SHI	23.94 (6.02)	21.86 (6.45)	2.664 (.106)	(1,94)
ESS	8.06 (4.27)	8.12 (4.01)	.005 (.945)	(1,94)
Sleep Efficiency	86.48 (10.24)	89.20 (9.95)	1.743 (.190)	(1,94)

Effects for Sleep Problems Groups. Regarding differences between continuous variables, scores on alcohol measures, and scores on sleep measures between participants with sleep problems (PSQI >7) compared to those without sleep problems (Table 3.4), there were significant differences in expected semester GPA (p = .019). Specifically, individuals who reported sleep problems had significantly less expected GPA for that semester. As expected, there were significant differences between the sleep measures, with the sleep problems group endorsing higher scores on the PSQI, SHI, and sleep efficiency (p < .001). Unexpectedly, there was not a significant in amount of daytime sleepiness between groups as measured by the ESS (p = .100). There were no significant differences between age, current GPA, hours studying per week, percentage of free time busy, number of caffeinated beverages drank per day, and scores on the AUDIT, RAPI, and B-YAACQ (p > .05).

Table 3.4. *Demographic and Psychological Measure Means and Differences for Sleep Problems*

	Sleep Problems M (SD)	No Sleep Problems M (SD)	ANOVA *F (p)*	*df*
Age	19.94 (2.23)	20.52(2.42)	1.498 (.224)	(1,94)
GPA	3.386 (.417)	3.497 (.446)	1.06 (.307)	(1,62)
Expected GPA	3.505 (.397)	3.681 (.310)	5.657(.019)	(1,92)
Hours Studying	15.13 (10.92)	17.50 (9.42)	1.241 (.268)	(1,92)
% of Time Busy	41.44 (25.19)	39.14 (27.93)	.181 (.672)	(1,94)
Caffeine Drinks	1.30 (1.22)	1.38 (1.25)	.093 (.761)	(1,94)
AUDIT	4.69 (3.43)	4.25 (4.15)	.327 (569)	(1,94)
RAPI	3.52 (4.09)	2.91 (4.14)	.526 (.470)	(1,94)
BYAACQ	4.37 (3.80)	3.20 (4.41)	1.927 (.168)	(1,93)
PSQI	8.48 (2.54)	3.91 (1.10)	123.02 (< .001)	(1,94)
SHI	25.35 (5.27)	19.95 (6.20)	21.22 (< .001)	(1,94)
ESS	8.73 (4.15)	7.34 (3.99)	2.767 (.100)	(1,94)
Sleep Efficiency	83.99 (11.61)	92.45 (5.22)	19.881 (< .001)	(1,94)

Tables 3.5, 3.6, and 3.7 show correlation matrices for categorical and continuous demographic variables, as well as scores on alcohol and sleep measures with performance on all cognitive tasks. After preliminary analyses regarding the sampling distribution and demographic differences between the alcohol use and sleep problems groups, several variables were identified to be significantly different between one or both groups.

Specifically, Greek status, expected GPA, and number of hours per week spent studying significantly differed between one or both groups. As such, these variables will be included as covariates in the univariate ANOVA models.

Table 3.5. *Bivariate Correlations for Demographic Variables and Cognitive Performance*

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Age	--														
2	Year	.734**	--													
3	Gender (Female=1)	-.244*	-.176	--												
4	Greek Status (Greek=1)	-.240*	-.184	.239*	--											
5	Employed	.196	.388**	.196	.017	--										
6	MH Probs	.006	-.066	.229*	-.049	.167	--									
7	Composite	.065	.144	-.058	.03	-.002	.143	--								
8	Verbal Learning	.048	.177	.164	.167	.164	.024	.287**	--							
9	Flanker	.182	.257*	.047	.04	.042	-.055	.502**	.325**	--						
10	List WM	-.117	.015	.114	.132	-.025	.124	.519**	.251*	.460**	--					
11	Oral Reading	-.036	.13	.028	.036	.076	.132	.855**	.235*	.386**	.458**	--				
12	Oral Symbol	-.165	-.145	.142	.063	-.176	.01	.410**	.285**	.419**	.499**	.376**	--			
13	Pattern Processing	-.266**	-.034	.113	.119	.127	-.013	.283**	.235*	.424**	.441**	.223*	.362**	--		
14	Picture Sequence	-.102	.073	.171	.173	-.063	-.136	.281**	.354**	.319**	.392**	.278**	.460**	.341**	--	
15	Picture Vocabulary	.114	.085	-.067	.042	-.102	.165	.850**	.239*	.458**	.415**	.532**	.327**	.223*	.196	--

Note. * = correlation significant at the .05 level. ** = correlation significant at the .01 level

Table 3.6. *Bivariate Correlations for Demographic Variables and Cognitive Performance*

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	% Free Time Busy	--													
2	GPA	.036	--												
3	Hours/week Studying	-.023	.098	--											
4	Expected GPA	-.105	.697**	.217*	--										
5	Daily Caffeine Use	.064	-.272*	.104	-.059	--									
6	Composite	.128	.203	.021	.201*	.068	--								
7	Verbal Learning	.057	.114	.11	.227*	.009	.287**	--							
8	Flanker	.18	.18	.083	.235*	.137	.502**	.325**	--						
9	List WM	.114	.199	-.14	.081	-.074	.519**	.251*	.460**	--					
10	Oral Reading	.114	.192	.071	.202*	-.077	.855**	.235*	.386**	.458**	--				
11	Oral Symbol	.008	.242	-.069	.309**	-.079	.410**	.285**	.419**	.499**	.376**	--			
12	Pattern Processing	.036	.231	-.064	.212*	-.045	.283**	.235*	.424**	.441**	.223*	.362**	--		
13	Picture Sequence	0.006	.341**	-.231*	.231*	-0.150	.281**	.354**	.319**	.392**	.278**	.460**	.341**	--	
14	Picture Vocabulary	0.089	0.191	-0.074	0.143	0.194	.850**	.239*	.458**	.415**	.532**	.327**	.223*	0.196	--

Note. * = correlation significant at the .05 level. ** = correlation significant at the .01 level.

Table 3.7. *Bivariate Correlations for Alcohol and Sleep Measures and Cognitive Performance*

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	AUDIT	--														
2	RAPI	.603**	--													
3	B-YAACQ	.758**	.659**	--												
4	PSQI	.055	-.013	.143	--											
5	SHI	.083	.181	.232*	.454**	--										
6	ESS	.022	.222*	.079	.218*	.302**	--									
7	Composite	-.183	-.104	-.129	-.264**	-.362**	-.114	--								
8	Verbal Learning	-.054	.16	.117	-.215*	-.142	.037	.287**	--							
9	Flanker	-.119	.042	-.097	-.201*	-.345**	-.091	.502**	.325**	--						
10	List WM	-.161	-.046	-.137	-.174	-.199	-.007	.519**	.251*	.460**	--					
11	Oral Reading	-.174	-.138	-.175	-.309**	-.379**	-.192	.855**	.235*	.386**	.458**	--				
12	Oral Symbol	-.133	-.058	-.151	-.265**	-.176	-.003	.410**	.285**	.419**	.499**	.376**	--			
13	Pattern Processing	.038	.184	.07	-.214*	-.144	-.018	.283**	.235*	.424**	.441**	.223*	.362**	--		
14	Picture Sequence	.027	.043	-.094	-.162	-.187	.005	.281**	.354**	.319**	.392**	.278**	.460**	.341**	--	
15	Picture Vocabulary	-.133	-.048	-.041	-.082	-.206*	-.016	.850**	.239*	.458**	.415**	.532**	.327**	.223*	.196	--

Note. * = correlation significant at the .05 level. ** = correlation significant at the .01 level.

Main Effects on Cognitive Performance

Hypothesis 1a. To test for differences in cognitive performance between the alcohol use groups, One-way ANOVAs were conducted using each of the NIH Toolbox tasks as outcome variables. Table 3.8 presents mean differences on cognitive performance tasks for participants who endorsed binge drinking, as compared to those who do not binge drink. There was a significant difference between groups in performance on the Auditory Verbal Learning Task (p = .035) when using a conventional *p*-value of .05; however, these effects were not significant after correcting for alpha inflation. There were no significant differences in performance on any other subtests or scores gathered from the NIH Toolbox Cognitive Battery.

Table 3.8. *Cognitive Measure Means and Main Effects for Alcohol Use Groups*

	Binge Drinker M (SD)	Non-Binge M (SD)	ANOVA *F (p)*	*df*
Verbal Learning Raw Score	27.87 (5.78)	30.35 (5.55)	4.578 (.035)	(1,94)
Flanker Inhibitory SS	102.81 (6.43)	106.00 (9.50)	3.687 (.058)	(1,94)
Flanker Computed Score	8.239 (.62)	8.891 (.54)	2.159 (.143)	(1.94)
List Working Memory SS	106.87 (10.63)	110.92 (11.57)	3.177 (.078)	(1,94)
Oral Symbol Raw Score	98.85 (16.69)	104.80 (18.92)	2.658 (.106)	(1,94)
Pattern Processing SS	121.62 (15.70)	123.78 (16.90)	.420 (.519)	(1,94)
Picture Sequence Mem. SS	115.09 (15.52)	117.65 (13.77)	.737 (.393)	(1,94)
Picture Vocabulary SS	100.79 (8.61)	104.06 (13.42)	2.006 (.160)	(1,94)

Hypothesis 1b. To test for differences in cognitive performance between the sleep problems groups, One-way ANOVAs were conducted using each of the NIH Toolbox tasks as outcome variables. Table 3.9 presents mean differences on cognitive performance tasks for participants who were identified as having sleep problems compared to those who do not have sleep problems. There was a significant difference between groups in performance on Flanker Inhibitory Control and Attention Test (p = .019), and Oral Symbol Digit Test (p = .021) when using a conventional *p*-value of .05;

however, these effects were not significant after correcting for alpha inflation. There were no significant differences in performance on any other subtests or scores gathered from the NIH Toolbox Cognitive Battery.

Table 3.9. *Cognitive Measure Means and Main Effects for Sleep Problems Groups*

	Sleep Problems M (SD)	No Sleep Problems M (SD)	ANOVA *F (p)*	*df*
Verbal Learning Raw Score	28.31 (5.49)	30.11 (6.00)	2.368 (.127)	(1,94)
Flanker Inhibitory SS	102.63 (7.22)	106.57 (8.95)	5.678 (.019)	(1,94)
Flanker Computed Score	8.197 (.63)	8.927 (.53)	2.879 (.101)	(1.94)
List Working Memory SS	107.35 (10.25)	110.82 (12.16)	2.304 (.132)	(1,94)
Oral Symbol Raw Score	98.02 (18.02)	106.45 (17.11)	5.471 (.021)	(1,94)
Pattern Processing SS	120.98 (17.26)	124.77 (14.96)	1.298 (.257)	(1,94)
Picture Sequence Mem. SS	115.54 (15.86)	117.41 (13.13)	.387 (.535)	(1,94)
Picture Vocabulary SS	101.73 (10.13)	103.32 (12.77)	.461 (.499)	(1,94)

Regression Effects of PSQI on Cognitive Performance

In an effort to fully capture the effects of sleep performance (as measured by the PSQI) on cognitive variables, linear regression analyses were conducted using PSQI score as an independent variable and each cognitive score as the dependent variable. Table 3.10 represents the proportion of variance for each variable that can be accounted for by scores on the PSQI, the unstandardized coefficient with associated standard error, as well as the *F* test and p-value of the tested regression. Results were similar to ANOVA results, indicating the PSQI had significant relationships with the Flanker Inhibitory Control and Attention Task and the Oral Symbol Digit Test. Specifically, results indicated that for each 1-point increase on the PSQI, participants' standard score on the Flanker decreased by .485 points. This adds evidence that sleep problems may lead to decreases abilities to attend to important stimuli and ignore irrelevant stimuli. Results also showed that for each 1-point increase on the PSQI, participants tended to have .582

less responses on the Oral Symbol Digit Test. This result indicated that people with lower PSQI scores tended to have better verbal processing speed abilities. Additionally, there was a significant relationship with the PSQI and the computed scored on the Flanker Inhibitory Control and Attention Test, indicating that for each 1-point increase on the PSQI, participants' computed score decreased by .064 points (out of 10). This result indicated that participants with lower PSQI scores tended to have better accuracy and faster reaction times on the Flanker Task.

Table 3.10. *Cognitive Measure Regression Results for Sleep Problems Measured by PSQI*

	R^2	*F* (1,94)	B *(S.E.)*	*p*
Verbal Learning Raw Score	.046	3.031	-.171 (.181)	.091
Flanker Inhibitory SS	.041	7.268	-.485 (.268)	.012
Flanker Computed Score	.058	12.589	-.064 (.046)	.003
List Working Memory SS	.031	2.949	-.362 (.199)	.095
Oral Symbol Raw Score	.040	7.003	-.582 (.288)	.015
Pattern Processing SS	.046	3.161	-.291 (.210)	.090
Picture Sequence Mem. SS	.026	.589	-.115 (.139)	.384
Picture Vocabulary SS	.007	.637	-.137 (.143)	.359

Additional Analyses for Reaction Times

In addition to standard and computed scores for administered subtests, trial accuracy and reaction times were analyzed for potential interactions with binge drinking and sleep problems. Regarding the Flanker Inhibitory Control and Attention Test, there were 2 incorrect responses (both on incongruent trials) out of 1,920 total trials, indicating a 99.90% accuracy rate. For subsequent analyses, these two incorrect responses were omitted from the analyses. When comparing reaction times for congruent and incongruent trials, results indicated that participants were significantly slower in responding to incongruent trials compared to congruent trials ($F(1,1916) = 18.612$, $p < .001$). Reaction times on congruent trials averaged 631 ms with a standard deviation of

170, while the incongruent trials averaged 675 ms with a standard deviation of 184. Factorial ANOVAs were also conducted to analyze how the reaction times on congruent and incongruent trials may interact with the alcohol use and sleep variables. Using a 2x2 ANOVA with type of trial (congruent vs. incongruent) and alcohol use (binge drinker vs. non-binge drinker) as independent variables, there was a significant main effect for type of trial ($F(1,92) = 11.481$, $p < .001$), but the main effect for alcohol use ($F(1,92) = 1.308$, $p = .256$) as well as the interaction ($F(1,92) = .691$, $p = .408$) did not exhibit significant differences. A similar pattern was found when conducting a 2x2 ANOVA with type of trial and sleep problems as independent variables. There was a significant main effect for type of trial ($F(1,92) = 14.182$, $p < .001$), but the main effect for sleep problems ($F(1,92) = 2.719$, $p = .103$) as well as the interaction effect ($F(1,92) = .821$, $p = .367$) did not exhibit significant differences.

Factorial Effects on Cognitive Performance

Hypothesis 1c. To examine the main and interactive effects of alcohol use and sleep problems on cognitive performance, univariate ANOVAs were used on each cognitive performance outcome measure with alcohol use (binge, non-binge) and sleep problems (sleep problems, no sleep problems) as fixed factors. Because there were significant main effect differences between the independent variables (alcohol use and sleep problems) on several demographic factors (Greek status, expected GPA, hours spent studying), each of these was tested as a covariate in factorial ANCOVAs for each cognitive performance variable. However, none of these variables were significant covariates in the univariate ANCOVAs, therefore no covariates were used for the final analyses. Table 3.11 shows the results of the univariate ANOVA performed for each cognitive performance outcome.

Table 3.11. *Univariate Main Effects and Interactions for Cognitive Performance Variables*

	ALCOHOL *F (p)*	SLEEP *F (p)*	Alcohol*Sleep *F (p)*	*df*
Verbal Learning Raw Score	3.577 (.062)	1.596 (.210)	.084 (.773)	(1,92)
Flanker Inhibitory SS	2.730 (.102)	4.420 (.038)	.258 (.612)	(1,92)
Flanker Computed Score	.549 (.462)	.220 (.640)	.310 (.579)	(1,92)
List Working Memory SS	2.637 (.108)	1.549 (.216)	.370 (.545)	(1,92)
Oral Symbol Raw Score	1.688 (.197)	4.495 (.037)	.027 (.871)	(1,92)
Pattern Processing SS	.389 (.534)	.973 (.326)	2.165 (.145)	(1,92)
Picture Sequence Mem. SS	.694 (.407)	.215 (.644)	.512 (.476)	(1,92)
Picture Vocabulary SS	1.879 (.174)	.200 (.656)	.367 (.546)	(1,92)

Regarding the Flanker Inhibitory Control and Attention Test, the factorial ANOVA results mirrored the results from the One-Way ANOVA, indicating a significant main effect for the sleep problems groups, with participants below the clinical cutoff for sleep problems performing better at attending to relevant stimuli and ignoring irrelevant stimuli. For the alcohol main effect, there was not a significant difference, and there was not a significant interaction between the variables ($p > .05$). For the Oral Symbol Digit Test, results also paralleled the One-Way ANOVA results such that there was a significant main effect for the sleep problems groups (indicating participants below the cutoff for sleep problems exhibited faster processing speed abilities), and not significant main effects for the alcohol groups. There was not a significant interaction between the variables ($p > .05$). When examining factorial ANOVA results for subtests and scores attained, there were no main effects for either the alcohol groups or the sleep problems groups, and there was also a non-significant interaction between the variables ($p > .05$).

Exploratory Analyses for Factorial Effects

Due to the non-significant interactive effects of the factorial models, we conducted exploratory analyses with data from participants selected to represent the hypothesized effects between individuals without sleep problems who do not drink compared to individuals who binge drink and have significant sleep problems. We identified three participants who reported not drinking alcohol and endorsing minimal issues with sleep (PSQI ≤ 2), as well as four participants who endorsed binge drinking within the monitoring period and having significant issues with sleep (PSQI ≥ 11). Table 3.12 shows mean scores for each of the cognitive performance outcome variables for the two groups, as well as results of the One-Way ANOVA test and a measurement of effect size (Cohen's d).

Table 3.12. *Means, Main Effects, and Effect Sizes for Exploratory Analyses*

	No Alcohol or Sleep Problems M (SD)	Binge Drinking with Sleep Problems M (SD)	ANOVA *F(1,5) (p)*	*Cohen's d*
Verbal Learning Raw Score	35.667 (4.04)	31.5 (2.65)	2.772 (.157)	1.272
Flanker Inhibitory SS	102.333 (10.41)	94.5 (5.68)	1.677 (.252)	.989
Flanker Computed Score	8.597 (.67)	8.425 (.30)	.219 (.660)	.357
List Working Memory SS	103.67 (11.37)	97 (6.98)	.941 (.376)	.741
Oral Symbol Raw Score	102 (15.72)	86.75 (5.5)	3.409 (.124)	1.410
Pattern Processing SS	123.67 (7.51)	116.25 (16.40)	.513 (.506)	.547
Picture Sequence Mem. SS	117.67 (9.87)	103.75 (10.56)	3.136 (.137)	1.352
Picture Vocabulary SS	114 (13.89)	93.75 (19.82)	2.246 (.194)	1.145

When examining effect sizes, all of the group differences exhibited medium or large effects with the exception of the Flanker Computed Score. Typical categorization of Cohen's d states that scores of .02 are consider small effects, scores of .05 are considered medium effects, and scores of .08 are considered large effects (Klein et al., 2007). Cognitive measures exhibiting medium effect sizes are reaction time on the Flanker Task, the List Sorting Working Memory Test (which measures working memory capabilities), and the Pattern Comparison Processing Speed Test (which measures processing speed abilities). Cognitive measures exhibiting large effect sizes are the Auditory Verbal Learning Test (which measures episodic memory), the Flanker Inhibitory Control and Attention Test (which assesses inhibitory control and attention), the Oral Symbol Digit Test (which assesses verbal processing speed abilities), the Picture Sequence Memory Test (which also assesses episodic memory), and the Picture Vocabulary Task (which measures long-term acquired memory). Overall results of these exploratory analyses show promising trends for the hypothesized multiplicative effect of binge drinking and sleep disruption on cognitive performance.

Daily Alcohol Use and Sleep Behaviors

Preliminary analyses were conducted to verify that multilevel modeling (MLM) was appropriate for outcome data. First, intercept only models were run to ensure daily outcome variables significantly differed from zero. Table 3.13 shows y-axis intercepts (means) for selected variables. Second, between group variability analyses were conducted to determine if there was significant variability of outcome variables between groups (participants). If there is significant variability, that is an indicator that MLM is an appropriate statistical approach (Tabachnick & Fidell, 2007). Table 3.14 shows the variability components for each of the outcome variables. Interclass correlations (ICC) were also calculated as another indicator for the suitability of using MLM (Table 3.15). Tabachnick and Fidell (2007) report that ICCs as low .01 can result in bias without using a multilevel modeling approach. The following model was used for each of the outcome variables for the preliminary analyses:

Level-1 Model

$Variable_{ij} = \beta_{0j} + r_{ij}$

Level-2 Model

$\beta_{0j} = \gamma_{00} + u_{0j}$

Mixed Model

$Variable_{ij} = \gamma_{00} + u_{0j} + r_{ij}$

Table 3.13. *Intercept Analyses for Outcome Variables*

Fixed Effect	Coefficient	S.E.	*t*-ratio	*d.f.*	*p*-value
Intercept, β_0					
Daily Drinks, γ_{00}	1.510	0.203	7.434	95	<0.001
Bedtime, γ_{00}	13.248	0.122	108.243	95	<0.001
Wake Time, γ_{00}	8.373	0.077	108.359	95	<0.001
Time in Bed, γ_{00}	7.115	0.092	77.349	95	<0.001
Sleep Quality, γ_{00}	7.490	0.071	104.820	95	<0.001

Table 3.14. *Between Group Variability for Outcome Variables*

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
Daily Drinks, u_0	1.622	2.630	95	282.540	<0.001
level-1, *r*	3.054	9.327			
Bedtime, u_0	1.070	1.143	95	463.394	<0.001
level-1, r	1.437	2.064			
Wake Time, u_0	0.628	0.394	95	304.533	<0.001
level-1, r	1.119	1.252			
Time in Bed, u_0	0.712	0.508	95	253.267	<0.001
level-1, r	1.460	2.133			
Sleep Quality, u_0	0.397	0.157	95	139.891	0.002
level-1, r	1.526	2.330			

Table 3.15. *Interclass Correlations for Outcome Variables*

Variable	ICC Value
Daily Drinks	.220
Bedtime	.356
Wake Time	.240
Time in Bed	.192
Sleep Quality	.063

To determine suitability for MLM analyses, a random intercept model was tested for all outcome variables (Daily Drinks, Bedtime, Wake Time, Time in Bed, and Subjective Sleep Quality) with 672 nights of data nested within 96 participants. The intercept coefficient for all outcome variables significantly differed from zero (all p’s $<.001$), and indicated participants drank an average of 1.51 drinks per day, had an average bedtime of 1:15 AM, an average wake time of 8:22 AM, an average time in bed of 7.11 hours (7 hours 7 minutes), and had an average subjective sleep quality of 7.49 (out of 10) per night. Furthermore, there was significant between group variability for all outcome variables (all p’s $<.003$), indicating the variables randomly varied across participants. The ICC values for each variable (except sleep quality) indicated that a notable proportion of the total variance was between participants. Overall, there were multiple indicators that MLM was an appropriate approach to testing the daily reports of drinking and sleeping behaviors.

To assess for systematic linear changes of drinking and sleeping behaviors during the week prior to assessment, multilevel growth models were tested using days passed as a Level-1 slope parameter. The day of the assessment was coded as “0” so the outcome coefficient can be interpreted as the average for the day before the participant came in for the laboratory portion of the experiment. These models will not only allow interpretation of how sleeping and drinking behaviors change over the week prior to assessment, but will also establish a baseline of these variables directly prior to assessment. Therefore, it will allow better inference of how these behaviors may impact score on the cognitive tasks. The following model was used for all variables:

Level-1 Model

$Variable_{ij} = \beta_{0j} + \beta_{1j}*(DAY_{ij}) + r_{ij}$

Level-2 Model

$\beta_{0j} = \gamma_{00} + u_{0j}$

$\beta_{1j} = \gamma_{10} + u_{1j}$

Mixed Model

$Variable_{ij} = \gamma_{00} + \gamma_{10}*DAY_{ij} + u_{0j} + u_{1j}*DAY_{ij} + r_{ij}$

Table 3.16. *Intercept Coefficient and Linear Change of Outcome Variables*

Fixed Effect	Coefficient	S.E.	*t*-ratio	*d.f.*	*p*-value
Daily Drinks, γ_{00}	0.087	0.171	0.511	95	0.610
Day Slope, γ_{10}	-0.474	0.081	-5.845	95	<0.001
Bedtime, γ_{00}	12.807	0.124	103.679	95	<0.001
Day Slope, γ_{10}	-0.147	0.021	-6.956	95	<0.001
Wake Time, γ_{00}	8.341	0.126	66.042	95	<0.001
Day Slope, γ_{10}	-0.010	0.023	-0.454	95	0.651
Time in Bed, γ_{00}	7.517	0.079	94.651	95	<0.001
Day Slope, γ_{10}	0.134	0.015	8.926	95	<0.001
Sleep Quality, γ_{00}	7.624	0.091	84.063	95	<0.001
Day Slope, γ_{10}	0.045	0.024	1.892	95	0.062

Table 3.17. *Between Group Variability for Outcome Variables*

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
Daily Drinks, u_0	0.119	0.014	95	7.631	>0.500
Day Slope, u_1	0.646	0.417	95	224.211	<0.001
level-1, r	2.452	6.012			
Bedtime, u_0	0.925	0.856	95	155.267	<0.001
Day Slope, u_1	0.049	0.002	95	58.994	>0.500
level-1, r	1.397	1.951			
Wake Time, u_0	1.009	1.019	95	269.831	<0.001
Day Slope, u_1	0.125	0.016	95	116.681	0.065
level-1, r	1.083	1.174			
Time in Bed, u_0	0.531	0.282	95	61.940	>0.500
Day Slope, u_1	0.064	0.004	95	28.874	>0.500
level-1, r	1.422	2.021			

Sleep Quality, u_0	0.278	0.077	95	70.788	>0.500
Day Slope, u_1	0.043	0.002	95	62.285	>0.500
level-1, r	1.519	2.306			

Results from Table 3.16 indicate average values for outcome variables for the day prior to completing the in lab cognitive task, as well as the degree of systematic change for the variables during the week of monitoring prior to the in-lab assessment. Participants averaged having .09 alcoholic drinks during the night before assessment. There was also a significant systematic increase of .47 drinks ($p < .001$) for each additional day prior to the in-lab assessment. Participants had an average bedtime of ~12:48 AM the night prior to assessment, with a systematic increase of 8.82 minutes ($p < .001$) for each additional night prior to assessment. Participants had an average wake time of ~8:20 AM the morning of assessment, but did not exhibit a systematic change of wake time during the week prior to assessment ($p = .651$). Participants averaged 7 hours 31 minutes of time in bed for the night prior to the in-lab portion and had a systematic decrease of time in bed duration of 8 minutes ($p < .001$) for each additional night prior to assessment. Finally, participants reported an average sleep quality of 7.62 (out of 10) for the night prior to assessment. Although it was not a significant value ($p = .062$), participants on average reported a decrease of sleep quality by .05 points for each additional night prior to the in-lab assessment.

Results from Table 3.17 illustrate the presence of between participant variability for outcome variables at time “0” (the day before in-lab cognitive assessment). Results also test for between participant variability of the day slope, which illustrates whether there is a significant difference in the rate of change over time between participants for the given outcome variables. For number of daily drinks, there was not a significant difference ($p > .500$) between participants for the amount of drinks the night prior to in-lab assessment, but there was significant variability ($p < .001$) between participants in the rate of change in number of daily drinks during the monitoring period. This indicates that participants tended to drink about the same amount the night prior to assessment, but had significantly different rates they drank throughout the previous week (e.g., some participants had greater linear trajectories of drinking during the week prior to assessment). Participants' bedtimes exhibited significant between person variability for the night before assessment ($p < .001$), but did not have significant variability in the rate of change during the prior week ($p > .500$). Participants' wake times exhibited a similar pattern in that there was significant between person variability in when they woke up the morning of assessment ($p < .001$), but tended to change at a comparable rate throughout the week ($p = .065$). For both time in bed and subjective sleep quality, there was no evidence of between person variability for averages the day before assessment ($p > .500$) or the rate at which the variables changed for the previous week ($p > .500$).

Assessing for Weekend Alcohol Use and Sleep Behaviors

To assess for systematic linear changes of alcohol use and sleeping behaviors specifically going into the weekend, participants' "DAY" variables were recoded so that the assessment period was consistent across participants. For each participant, the Thursday prior to their in-lab assessment was coded 0, with prior days proceeding in a negative direction and subsequent days proceeding in a positive direction. By using this recoding procedure, we will be able to assess average alcohol use and sleep behaviors for that particular Thursday, as well as the average change of the behaviors over the weekend.

Table 3.18 indicates average values for outcome variables for the Thursday prior to participants completing the in lab cognitive task, as well as the degree of systematic change for the variables heading into the weekend. On average, participants drank 2.4 alcoholic drinks on Thursday night, with an average increase of .68 drinks each day thereafter ($p < .001$). On the Thursday before assessment, participants had an average bedtime of 1:32 AM, with a systematic increase of 27 minutes on each subsequent night ($p < .001$). Participants had an average wake time of ~8:26 AM the Thursday prior to assessment, and did not exhibit a systematic change of wake time during the week prior to assessment ($p = .484$). Participants averaged 6 hours 53 minutes of time in bed for the Thursday prior to the in-lab portion, and had a systematic increase of time in bed duration of 19 minutes ($p < .001$) for each night thereafter. Finally, participants reported an average sleep quality of 7.39 (out of 10) for the Thursday night prior to assessment, with that rating increasing by .05 points each night afterwards ($p = .011$).

Results from Table 3.19 illustrate the presence of between participant variability for outcome variables at time “0” (the Thursday before in-lab cognitive assessment). Results also test for between participant variability of the day slope, which illustrates whether there is a significant difference in the rate of change over time between participants for the given outcome variables. For number of alcoholic drinks, there was a significant difference between participants for the amount of drinks they had on Thursday night, as well as significant variability in the rate at which their drinking changed over time. This indicated that some participants tended to have a greater slope than others, indicating their drinking increased at higher levels over time than others. Participants' bedtimes exhibited significant between person variability for the Thursday night before assessment ($p < .001$), but did not have significant variability in the rate of change during the week ($p > .500$). Participants' wake times exhibited a similar pattern in that there was significant between person variability in when they woke up the Thursday before the in-lab portion ($p < .001$), but tended to change at a comparable rate throughout the week ($p = .080$). This pattern continued for both the time in bed and sleep quality variables, indicating participants tended to have variability between their Thursday scores, but did not differ in the rate the scores changed.

Table 3.18. *Intercept Coefficient and Linear Change of Outcome Variables*

Fixed Effect	Coefficient	S.E.	*t*-ratio	*d.f.*	*p*-value
Daily Drinks, γ_{00}	2.396	0.341	7.010	95	<0.001
Day Slope, γ_{10}	0.681	0.372	6.572	95	<0.001
Bedtime, γ_{00}	13.523	0.136	99.032	95	<0.001
Day Slope, γ_{10}	0.442	0.126	6.818	95	<0.001
Wake Time, γ_{00}	8.415	0.069	120.301	95	<0.001
Day Slope, γ_{10}	0.015	0.021	0.703	95	0.484
Time in Bed, γ_{00}	6.875	0.114	60.117	95	<0.001
Day Slope, γ_{10}	0.324	0.027	5.578	95	<0.001
Sleep Quality, γ_{00}	7.390	0.086	85.014	95	<0.001
Day Slope, γ_{10}	0.051	0.020	2.581	95	0.011

Table 3.19. *Between Group Variability for Outcome Variables*

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
Daily Drinks, r_0	3.061	9.371	95	549.64	<0.001
Day slope, r_1	0.562	0.316	95	210.21	<0.001
level-1, e	2.530	6.404			
Bedtime, u_0	1.160	1.346	95	320.02	<0.001
Day Slope, u_1	0.044	0.001	95	57.98	>0.500
level-1, r	1.405	1.975			

Wake Time, u_0	0.468	0.219	95	160.44	<0.001
Day Slope, u_1	0.108	0.011	95	112.72	0.080
level-1, *r*	1.094	1.198			
Time in Bed, u_0	0.846	0.716	95	205.93	<0.001
Day Slope, u_1	0.058	0.003	95	28.08	>0.500
level-1, *r*	1.432	2.053			
Sleep Quality, u_0	0.464	0.216	95	120.26	0.030
Day Slope, u_1	0.037	0.001	95	59.41	>0.500
level-1, *r*	1.530	2.341			

Exploratory Analyses

Several a priori models were tested to determine the effects of day-level and participant-level variables on outcome variables. The first set of models aimed to assess what factors influence daily drinking behaviors. Number of daily alcoholic drinks was set as the outcome variable, with the following level 1 or 2 variables as predictors for separate models: bedtime, Greek status, and expected GPA. The time variable was left from the previous model to control for any systematic changes during the prior week. Results indicated that the bedtime slope significantly predicted drinking behaviors (*t*-ratio(479) = 21.361, p <.001), such that for each hour later participants stayed awake, there was an average increase of 1.37 drinks that night. Expected GPA also significantly impacted daily drinking behaviors (*t*-ratio(94) = -2.175, p =.032), with each point increase on expected GPA decreasing the number of drinks by .43 on average. Greek status did not have a significant impact on number of daily drinks after controlling for systematic changes over time (p = .771).

Using bedtime as the outcome variable and number of drinks as the predictor variables, number of daily drinks significantly predicted bedtime (*t*-ratio(479) = 49.764, p <.001), with each drink resulting in nightly bedtime being delayed by ~22 minutes. Time in bed was also used as an outcome with number of drinks and composite cognitive score as predictor variables. Results indicated that number of drinks significantly affected the number of hours of sleep (*t*-ratio(479) = -33.258, $p < .001$), with each drink resulting in 16.2 minutes less sleep per night. Subjective sleep quality was also tested as an outcome variable with number of daily drinks, bedtime, and time in bed as predictors. Number of drinks significantly affected subjective sleep quality (*t*-ratio(479) = 29.826, $p < .001$), indicating that for each drink, participants reported their sleep quality decreased by .42 points. Surprisingly, neither bedtime nor time in bed had significant effects on subjective sleep quality.

CHAPTER 4: DISCUSSION

Even though there is much evidence to support the relationship between alcohol use and diminished cognitive performance (Barkley & Fischer, 2011; Hermens & Lagopoulos, 2018; Jacobus et al., 2013), as well as sleep disruption leading to decreased cognitive performance (Dawson & Reid, 1997; Lim & Dinges, 2010; Mander et al., 2014), very few studies have aimed to examine the relationship of all three variables simultaneously. The present study sought to examine the impact of alcohol use and sleep disruption on cognitive performance (both independently and multiplicatively) in a population of college students. A secondary goal of the study was to examine self-report "diaries" of daily alcohol use and sleep patterns to identify factors that may impact drinking and sleeping behaviors. Results of the study were mixed with aspects of Hypothesis 1 and Hypothesis 2 being both supported and not supported. Overall, the study illustrated how alcohol use and sleep disruption may impact the cognitive performance (and subsequent academic achievement) of college students, as well as examine the longitudinal interactions of daily alcohol use and sleep behaviors over a one-week monitoring period. Results like these may be helpful in guiding academic retention researchers to implement behavioral alcohol use and sleep education programs for college students, in hopes of improving academic performance.

Key Findings

Before exploring the findings related to the study's hypotheses, several patterns emerged when analyzing demographic data related to alcohol use, sleep patterns, and cognitive performance. Contrary to prior research (Brien et al., 2013; Lui, 2019), this sample did not exhibit a disproportionate amount of Greek individuals who endorsed binge drinking, as compared to the rest of the sample. One explanation for this pattern is that approximately one-third of the sample were first semester freshmen, who may not have had experiences related to binge drinking. Recent research has also found that young adult males are more likely to report increased drinking behaviors compared to females (Evans-Polce et al., 2020), but there were no differences in gender for binge drinking in the current sample. This is most likely related to the fact that males were underrepresented in the sample (14.5%). When analyzing frequency data of whether or not the sample had sleep problems, individuals who reported not being in a fraternity/sorority had disproportionately more sleep problems than their peers in the Greek system. 84.6% of individuals with sleep problems identified as being non-Greek, as compared to 63.6% of individuals who reported not having sleep problems being non-Greek. A study by Scott-Sheldon, Carey, and Carey (2008) found that Greek individuals reported significant differences in sleep duration, but did not report on overall sleep disruption/problems. The study also analyzed data from ~1,600 participants (compared to 96 in the current study), so similar patterns may evolve with more participants. Although not a significant difference (p =.07) there were trends towards upperclassmen reporting less sleep problems than underclassmen. Prior research has found significant changes in decreasing sleep problems as students progress through college (Taylor et al., 2005), attributing the differences to maturational changes of aging and more adaptive adjustment to college lifestyle.

When examining differences in demographic data and results from psychological measures for participants who endorsed binge drinking compared to those who did not, there were expectedly significant differences on scores of the three alcohol measures

(AUDIT, RAPI, B-YAACQ; all p's <.001). Contrary to existing literature (Conway & DiPlacido, 2015; Meda et al., 2017) there was not a significant difference between binge and non-binge groups on reported GPA. There was, however, a significant difference ($p = .018$) in report of expected GPA for the current semester, with individuals who did not report binge drinking expecting to have higher GPAs than those who do binge. This finding may be due in part to approximately one-third of the sample being first semester freshmen, who were instructed not to report an overall GPA (because they did not have one at the time). Perhaps a larger sample size or monitoring of actual GPAs once the semester is completed would result in significant differences between actual reported GPAs. Results also indicated a significant difference ($p = .034$) in the number of hours spent studying between those who binge drink and those who do not, with non-binge drinkers studying ~4.5 hours more each week. Although not much research has been done on the subject, similar results have been found in other studies (Clarke et al., 2018). These researchers explained the difference through other demographic variables (e.g., sports involvement), and the current sample may have other variables serving as mediators or moderators that may contribute to the difference.

When examining differences in demographic data and results from psychological measures for participants who endorsed sleep problems compared to those who did not, there were significant differences in two of the three sleep measures (PSQI and SHI) as well as overall scores of sleep efficiency (all p's <.001). Surprisingly, scores on the ESS did not differ for individuals who did and did not report sleep problems ($p = .100$). In a sample of young adults, Gelaye and colleagues (2014) attempted to identify the construct validity and factor structure of both the PSQI and ESS (two of the most commonly used measures for sleep). The researchers found that the PSQI resulted in a more robust measurement of overall sleep problems, whereas the ESS only measured the amount of sleepiness throughout the day. Other explanations for the differences may include daytime sleepiness only occurring in more severe cases of sleep problems, and young adults being less susceptible to daytime sleepiness than older adults (Gelaye et al., 2014). Like the binge drinking comparison, there was not a significant difference in GPA between the two sleep groups, but there was a difference in expected GPA, with individuals without sleep problems expecting to have a higher GPA for the semester. Explanations for these findings may be similar to before (small sample size, missing data from first semester students) as previous research has established that students with sleep problems tend to have lower overall GPAs (Hysing et al., 2016).

As a final step in the preliminary analyses, bivariate correlations were conducted with demographic data and scores on alcohol and sleep measures to evaluate their relationship with scores on tasks from the NIH Toolbox Cognitive Assessment. None of the three alcohol measures were significantly correlated with any of the subtests on the cognitive assessment. Although not directly using the NIH toolbox, many studies have examined the detrimental effects of alcohol use and binge drinking on attention, memory, executive functioning, and processing speed (e.g., Heffernan & O'Neill, 2012; Mota et al., 2013; Randall et al., 2004; Sanhueza et al., 2011; Weissenborn & Duka, 2003), constructs that are measured by tasks in the cognitive assessment. While it is unclear the reason for the nonsignificant relationships, it may be because college students tend to be higher functioning regarding cognitive performance, which may have resulted in a more homogeneous sample. Conversely, two of the three sleep measures (PSQI and SHI) were significantly associated with many of the tasks on the cognitive assessment. These relationships were all inverse in nature, meaning that higher scores on the sleep measures (indicating more sleep problems) were associated with lower scores on the cognitive tasks. These relationships were especially strong for measures of executive functioning, attention, and language skills. Another finding of note was that expected GPA was significantly associated with six cognitive tasks, whereas reported GPA was only associated with one of the cognitive tasks. These relationships were all positive, indicating participants who reported expecting a higher GPA tended to score higher on the cognitive assessment.

Hypothesis 1a. Hypothesis 1a examined the main effects of binge drinking on cognitive performance, as measured by performance NIH Toolbox Cognitive Assessment Battery. The hypothesis that individuals in the binge drinking group would score worse on cognitive tasks compared to individuals who did not report binge drinking was not supported after adjusting the alpha value for multiple comparisons. Only one of the tasks of the cognitive battery had significant differences in scores prior to the alpha correction (The Auditory Verbal Learning Test), with results indicating that participants who reported binge drinking recalled less words than those who do not endorse binge drinking ($p = .035$). Because participants are required to remember and recall a set of words presented verbally, this task assesses abilities in attention, and both short-term and working memory. This finding is consistent with current literature regarding binge drinking and attention (Randall et al., 2004; Sanhueza et al., 2011), as well as binge drinking and memory difficulties (Luna et al., 2010; Park & Kim, 2018). Scores on the Flanker Inhibitory Control and Attention Test exhibited differences approaching significance (p = .058) with individuals who binge drink performing worse on this task of attention and inhibitory control than those who do not. Another subtest that assesses attention and memory domains (The Picture Sequence Memory Test) showed no differences in performance between groups. Tasks assessing processing speed (Oral Symbol Digit Test and Pattern Comparison Processing Speed Test) and language skills (Picture Vocabulary Task) exhibited no differences between groups. There was also not a significant difference in reaction time in responding to items on the Flanker task. Previous research has found that while binge drinking can impair overall cognitive performance (particularly processing speed, memory, and language skills) while intoxicated, next day assessment shows no decline in performance (Affan et al., 2018; Howland et al., 2010). As none of the participants reported engaging in binge drinking the night prior to assessment, these results are not unexpected.

Hypothesis 1b. Hypothesis 1b examined the main effects of sleep problems on cognitive performance, as measured by the NIH Toolbox Cognitive Assessment Battery. The hypothesis that individuals who had sleep problems would score worse on cognitive tasks compared to individuals who did not report having sleep problems was not supported after adjusting the alpha value to correct for multiple group comparisons. Prior to adjusting the alpha level for multiple comparisons, results indicated differences between groups for two of the cognitive tasks given, each exhibiting that individuals who reported having sleep problems performed significantly worse than those who did not endorse sleep problems. Prior research has indicated that chronic sleep disruption can result in decreased cognitive abilities (Buboltz et al., 2009; Hilditch et al., 2016; Honn et al., 2019), so differences between groups were expected to be more prominent.

Significant differences in the Flanker Inhibitory Control and Attention Test were found prior to the alpha correction, indicating that individuals with sleep problems performed worse on attention and executive functioning than those that do not have sleep problems; however, other tasks assessing attention (Auditory Verbal Learning Task and Picture Sequence Memory Test) did not exhibit significant differences. Prior research has found a strong relationship with sleep problems and decreased attention (Dawson & Reid, 1997; Grant et al., 2017; Wesensten et al., 2005), as well as finding that attention is usually the first component of cognition to exhibit dysfunction with sleep problems (Dinges et al., 1997). These patterns within the study regarding sleep problems and attention could warrant further investigation. Another inconsistent finding was a significant difference prior to the alpha correction on the Oral Symbol Digit Test, indicating participants with sleep problems performed worse on a task of processing speed, while no differences were found on the Pattern Comparison Processing Speed Test and reaction time performance on the Flanker task (tasks that also assess for processing speed). Recent research has found that processing speed is significantly disrupted by sleep problems (Bradley et al., 2020; Schneider et al., 2016), so it is unclear why the differences would not be found on all tasks. An unexpected pattern of results appeared in that there were no significant differences between groups for any of the three tasks assessing memory functions (Auditory Verbal Learning Task, List Sorting Working Memory Test, and Picture Sequence Memory Test). Much of the current research is in agreeance that sleep problems result in significantly decreased memory functioning (Diekelmann & Born, 2010; Drummond et al., 2013; Lim & Dinges, 2010; McDevitt et al., 2015), so these non-significant findings could be indicative of a lack of power in the current sample.

In addition to examining the categorical nature of sleep problems achieved by a cutoff of 7 on the PSQI, regression analyses were conducted to assess for a more dimensional quality of sleep problems as measured by participants' responses to the PSQI. Results of regression analyses indicated more robust findings as four of the tested metrics exhibited significant results. Specifically, regression analyses indicated that as participants' scores on the PSQI increased (i.e., reported more problems associated with sleep), their performance on attention and processing speed tasks tended to decrease, as well as resulted in being less accurate with slower reaction times on tasks of inhibitory control. Prior research has found significant relationships in executive functioning, processing speed, and memory based on PSQI scores (Bernstein et al., 2019; Bolden et al., 2019).

Reaction Times and Accuracy Scores on Flanker Task. In addition to examining standard scores produced by the Flanker Task, accuracy scores and reaction times were examined to further explore the effects of alcohol use and sleep problems on cognitive performance. The first noteworthy result was the unusually high accuracy rate of the trials on the Flanker Task. Prior studies utilizing a Flanker Task exhibited accuracy rates averaging between 90% - 95% across all trials (Beaton et al., 2018; Bulger et al., 2021; Imburgio et al., 2020); however, the current study showed an accuracy rate of 99.8%. Another difference from previous studies using the Flanker Task was that the current study had an average reaction time of 650 ms while previous studies averaged 350 – 500 ms across trials (Beaton et al., 2018; Bulger et al., 2021; Imburgio et al., 2020). One explanation for the difference in reaction times could be the type of device with which the Flanker task was presented. Prior tasks using the Flanker were used on a computer screen and keyboard, with participants using two fingers on keys to quickly press a key based on the presented stimuli. The current study utilized an iPad presentation, with participants being instructed to use only one finger and return that finger to the desk between trials. This difference in presentation could explain the slower reaction times because the participants would have to move their finger from the desk to the iPad screen, instead of quickly pressing a button that their finger is already touching. These patters are consistent with a meta-analysis by Hedge and colleagues (2018) that showed positive correlations between reaction times and accuracy scores across multiple studies involving the Flanker task, as well as simulations conducted by the authors. That is to say that as reaction time increases (e.g., become slower), accuracy scores also increase. Therefore, it is possible to theorize that the extra time participants in the current study needed to move their finger could have led to more time to process the stimuli presented on screen and produce the correct response.

When analyzing reaction times between the congruent and incongruent trials, results indicated that the incongruent trials had significantly longer reaction times than the congruent trials. This pattern is both expected and consistent with prior literature involving the Flanker Task. The current study did not see a significant interaction or main effect when analyzing type of trial with the binge drinking and sleep problems variables. Prior studies have found that binge drinking leads to slower and more accurate responding on the Flanker Task (Connell et al., 2018), but results were moderated by depression scores among participants. Other research using participants who had or had not consumed alcohol found that participants who were intoxicated were more sensitive to errors on the Flanker Task, but the authors also noted that a variety of contextual factors may also impact performance (Bailey et al., 2014). Prior studies involving the Flaker Task and sleep have mainly focused on sleep deprivation, with results indicating the longer participants stay awake the more errors they are likely to make on the trials (Ko et al., 2015; Renn & Cote, 2013; Tsai et al., 2005). Although the current study did not exhibit significant results when using the clinical cutoff on the PSQI, perhaps future studies could utilize data from participants with severe sleep problems that would result in differences between reaction times on the Flanker Task trials.

Hypothesis 1c. Hypothesis 1c examined the multiplicative effects of binge drinking and sleep problems on cognitive performance, as measured by the NIH Toolbox Cognitive Assessment Battery. The hypothesis that there would be an interaction whereas participants who endorsed binge drinking and had sleep problems would score lower than all other groups was not supported. Regarding the main effects of binge drinking, there were no significant differences in any of the tasks after including sleep problems in the model. The main effects of sleep retained significant differences in the two cognitive tasks (Flanker Inhibitory Control and Attention Test and Oral Symbol Digit Test). Although the results were not as hypothesized, several of the subtests showed promise towards a significant interaction, which could indicate the need for a larger sample size to increase the power of the study.

In an effort to encapsulate the aforementioned results that showed that a larger (or perhaps more targeted) sample may lead to significant results, exploratory analyses were conducted with a small subset of participants that typified the alcohol use and sleeping behaviors that we anticipated would be more prevalent. We selected three participants that reported not engaging in any drinking behaviors, and that had scores on the PSQI of

2 or less (indicating minimal sleep difficulties). We compared this group to four selected participants that both endorsed engaging in binge drinking during the 1-week monitoring period, as well as having scores on the PSQI of 11 or higher. When examining the effect size of the differences between the groups, Cohen's d statistics ranged between .547 to 1.41 for all examined cognitive measures (excluding the computed score on the Flanker Task). These results indicated that effect sizes for the group differences would be considered medium to large, which showed evidence that our hypothesized effect would be present given the right sample composition. Future studies could screen for not only drinking behaviors, but sleeping behaviors as well to target participants on more extreme ends of sleep disruption, which would hopefully provide the sample needed to find significant multiplicative effects.

Hypothesis 2. Hypothesis 2 examined the daily alcohol use and sleep behaviors reported during the one-week monitoring period prior to the in-lab assessment. The hypothesis that there would be systematic linear changes over time for each of the variables was partially supported. When assessing daily alcohol use patterns, participants on average drank .09 drinks the night before assessment, and systematically increased drinking by .48 drinks for each day prior to assessment. Because participants were assessed during the week, the most likely explanation for this pattern is that the majority of drinking was done during the nights of Thursday, Friday, and Saturday. This pattern is consistent with prior research that college students tend to drink primarily on the weekend (Patrick et al., 2016). Results also indicated that participants' drinking slopes varied between participants, signifying that the rate of change for number of drinks was higher for some participants than others. This pattern is expected as because there were both drinkers and non-drinkers in the sample, the rate of change would be zero for non-drinkers and positively sloped for drinkers. When examining participants' bedtimes, there was an average reported bedtime of ~12:48 AM for the night prior to assessment, with a systematic linear increase of 8.82 minutes for each night prior to assessment. These results also indicated that the change tended to regress towards the weekend, which is consistent with other findings that college students tend to stay up later on the weekends (Bakotic et al., 2017; Van Reen et al., 2016). Results also showed that there was not between group variability in the rate of change over time, meaning that all students tended to go to bed later towards the weekend. When examining participants' wake times, results showed that on average participants woke up around 8:20 AM the morning of assessment, and there was no evidence of linear change throughout the week. There was also not significant between person variability, indicating that participants tended to wake up at a consistent time throughout the week. This finding is contrary to prior research showing college students wake up later on the weekends (Machado et al., 1998), but more recent literature is needed for this novel variable. Regarding participants' total time in bed, results indicated an average of 7.52 hours the night before assessment, and there was a systematic decrease of .13 hours (~8 minutes) for each night during the monitoring phase. These results are consistent with the bedtime and wake time findings of this study, in that students tended to go to bed later prior in the week, but maintained a consistent wake time. There was no evidence of between person variability, indicating all students tended to change over the week at the same rate. Finally, results of subjective sleep quality indicated participants reported an average of 7.62 (out of 10) for the sleep quality the night prior to assessment, and that this rating did not significantly change over the week. A study by Norbury and Evans (2019) that assessed the relationship between subjective sleep quality and mental health found that more than half of their sample of college students rated their sleep as “Fairly Good” or “Very Good”, indicating consistency with the findings of this study.

Additional Analyses. Using participant data from the monitoring period for the week prior to the in-lab assessment, several models were tested to determine variables that could predict daily alcohol use and sleeping behaviors. The aim of these models was to establish relationships not only between alcohol use and sleep patterns, but also if any demographic or cognitive factors could influence alcohol use and sleep. First, there was a bi-directional relationship between number of alcohol drinks consumed and nightly bedtime. Results indicated that for each drink participants consumed on a given night, their bedtime for that night was delayed by ~22 minutes. This finding indicates that if a male were to engage in binge drinking (5 or more drinks in a night), his bedtime could be delayed by almost 2 hours at minimum. Conversely, bedtime was also a significant predictor of number of drinks in a night, with each additional hour participants stayed awake resulting in an extra 1.37 drinks. This bi-directional relationship has been found in prior research using entirely binge drinking samples (Fucito et al., 2018), and it is interesting that this trend remains when including non-binge drinking participants.

Other models tested also resulted in significant predictors of alcohol use and nightly bedtime. When assessing for daily alcohol use, expected GPA significantly impacted drinking, such that for each point increase resulted in reducing the amount of drinks by .43. Again, while being statistically significant, the clinical implications are minimal. Another model tested the impact of Greek status on daily drinking, which surprisingly did not result in a significant relationship. This finding may be related to nuances in the sampling distribution as recent research has established a relationship between Greek affiliation and alcohol use (Luk et al., 2018; McCready, 2019).

Separate models were used to assess for the impact of number of alcoholic drinks on number of hours in bed and subjective sleep quality. Both models were significant, with each additional drink resulting in participants decreasing their time in bed by 16.2 minutes, as well as decreasing their subjective quality of sleep rating by .42. The practical implications of these findings are that if a male had a binge drinking episode (5 or more drinks in one sitting), he would decrease his total sleep time by at least one hour twenty minutes, and reduce his sleep quality rating by 2.1 (out of 10). These results illustrate how detrimental binge drinking episodes can be to nightly sleep functioning.

Limitations and Future Directions

Although the current study provided insight into the daily relationship of alcohol use and sleep patterns of college students, as well as how individuals with and without sleep problems and/or binge drinking perform on cognitive tasks, there are several limitations that may have impacted the current findings. The most prominent limitation is the number of participants that were able to complete the study. The a priori power analysis indicated that 130 participants would be necessary to achieve significant effects, whereas the current study was only able to collect complete data from 96 participants. Several factors led to the decreased number of completed participants, including participant no shows, research assistant attrition, and logistical issues. Future research would benefit from collecting data over multiple semesters as to anticipate no shows, as well as purchasing more equipment to be able to conduct multiple sessions at once.

Another limitation of the sample's generalizability was the low proportion of male participants that completed the study. Although recent research suggests between 30% - 40% of students in undergraduate psychology classes are male (Marulanda & Radtke, 2019), the current sample was only 14.6% male. Because the entire current sample came from participants getting credit for their psychology classes, perhaps advertising outside of the SONA system and offering monetary compensation would increase the proportion of male participants. Similarly, the current sample had an overrepresentation of participants identifying as European American (78.1%), which may limit the generalizability of the results to other areas with different demographic distributions. Although difficult to accomplish in a Midwestern university, future research at other sites may be able to obtain a better racial/ethnic distribution, which would increase the generalizability of the results.

A second limitation of the study is that all data collected besides the cognitive assessment was self-report in nature. Research has shown that self-report of potentially sensitive self-incriminating information (e.g., underage drinking) may result in socially desirable responses (Carey et al., 2001). Although participants were informed the data would remain confidential and explicitly encouraged answer as open and honestly as possible, there is still the possibility of socially desirable responding for self-report data. Another limitation of self-report data is the possibility of invalid responding patterns. Although there was no evidence of random or fixed (e.g., all zeros) responding, and none of the surveys were outliers for amount of time to complete (within two standard deviations of the average completion time), including attention checking questions within the measures could identify individuals who are not paying attention. The final limitation of self-report data for the study involved the reliability of the sleep behaviors and daily drinking diaries. Prior research has indicated that recall accuracy of sleep behaviors when asked to report more than 1-2 days prior tends to be unreliable (Broderick et al., 2013). Even though participants were asked to complete their diaries each morning, it is possible some participants did not comply with this suggestion. There were efforts made to increase reliable completion of the diary (i.e., participants received extra research credits for arriving with completed diaries), but still a few participants had to complete their diaries to the best of their abilities before they could participate in the study. Future studies could implement strategies such as participants completing their diaries daily in an online portal, or even utilize actigraphy to get more nuanced sleep data.

Another limitation of the study was the amount of days participants reported as having zero alcoholic drinks. Although this was expected when including a non-binge drinking sample, even the participants who endorsed binge drinking on the screening measure frequently had zero or one instance of drinking (and usually not binge drinking). Several factors such as time of semester (e.g., close to midterms or holidays), age (younger participants having difficulty obtaining alcohol), or social desirability may have impacted the amount participants reported drinking. Similar to sleep behaviors, self-report of alcohol use (especially number of drinks consumed) has been found to be unreliable when asked to recall further than the past week (Mason & Fleming, 2014). Although efforts were made in this study to ensure accuracy of reported alcohol use, future studies could implement an online portal for participants to record their drinking each day. Also increasing the monitoring period to two weeks before in-lab assessment would not only provide more sleep data, but also increase the likelihood of participants engaging in binge drinking during that timeframe.

Implications and Conclusions

The present study aimed to examine the differences in cognitive performance for students based on their binge drinking behaviors and/or sleep problems. A secondary goal for the study was to examine the relationships between self-report of daily alcohol use and sleep patterns. Main findings indicated that sleep problems seemed to impact overall cognitive performance more than binge drinking; however, very few participants engaged in binge drinking during the days prior to assessment. Secondary findings were notable mainly for illustrating the detrimental effects binge drinking has on bedtime, sleep quantity, and sleep quality. Although the current study did not find interactive effects for binge drinking and sleep problems on cognitive performance, this could be due to the sample being underpowered. Exploratory analyses of several "ideal" participants (those with no drinking behaviors and minimal sleep problems compared to those who engaged in binge drinking with significant sleep problems) indicated medium to large effect sizes on all but one of the cognitive measures. Future studies that could identify more targeted participant behaviors for inclusion would be more likely to identify significant multiplicative effects between alcohol use and sleep problems when examining cognitive performance.

Results of the MLM analyses of participants drinking and sleep diaries also provided useful information on how the two behaviors impact one another. Being able to predict how drinking behaviors impact same night sleep outcomes on average (e.g., the finding that participants on average slept 16 minutes less for each drink they consumed) would be beneficial information to convey to stereotypically “at risk” groups (e.g., fraternity members) or incoming Freshmen to make them more aware of the impact of these behaviors. Furthermore, results of the daily diaries may give researchers a more nuanced look into how alcohol use and sleep behaviors fluctuate throughout the week or even the semester. Researchers may be able to identify certain days where students are more likely to binge, which could lead to better education of students using protective behavioral strategies during those times to minimize harmful effects of binge drinking.

This study added to existing literature of two behavioral factors that could influence cognitive functioning, and subsequent academic performance in the classroom. These findings could be very beneficial to academic retention researchers, as they could use current findings as further evidence for why students should be educated on alcohol use and the importance of sleep. Programs like the Alcohol Skills Training Program (ASTP; Fromme et al., 1994) or the Brief Alcohol Screening and Intervention for College Students (BASICS; Dimeff et al., 1999) are effective at educating students about the impacts of their drinking behaviors, and the Sleep Treatment and Education Program for Students (STEPS; Brown et al., 2006) has been shown to improve sleep quality and sleep hygiene in college students. Perhaps combining these two approaches into one intervention would lead to benefits in both alcohol use and sleep behaviors, with the ultimate goal of reducing the negative impacts of these behaviors on academic performance.

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APPENDIX A: SLEEP DIARY

Start Date ____________   Participant Number_________

	Bedtime	Wake Time	# Alcoholic Drinks	Sleep Quality (1-10)
7 Nights Before				
6 Nights Before				
5 Nights Before				
4 Nights Before				
3 Nights Before				
2 Nights Before				
Night Before Study				

*Starting 7 nights before you are scheduled for the study, please note what time you went to bed, what time you woke up the next day (in the adjacent column), and how many drinks containing alcohol you had that night. Also note how you would rate the overall quality of your sleep with 1 being the worst and 10 being the best. For the most accurate reports, please complete each morning for the previous night's sleeping and drinking behaviors.